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A Possible Structure Model of the Vacuum

The Body Center Cubic Model of the Vacuum Material

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Abstract

This paper has deduced the baryon spectrum using only 2 flavored quarks u and d (each of them has three colored members). From Dirac's sea concept and the quark confinement idea, we conjecture and then assume that the quarks (in the vacuum state) compose colorless particles (uud and udd, hereafter will be called the **Lee Particles**). Moreover, the Lee Particles lead in a natural way to the construction - a body center cubic lattice in the vacuum. Consequently, there exists a strong interaction periodic field with body center cubic periodic symmetries and an electromagnetic interaction periodic field (from the charged Lee Particles uud) with simple cubic periodic symmetries in the vacuum. In terms of the energy band theory, using a point baryon approximation (i.e., omitting the structure of the Lee Particles), and from the symmetries of the strong interaction periodic field, we have deduced the intrinsic quantum numbers (I, S, C, b, Q) of all baryons and a unified mass formula from which all baryon masses can be found. This theoretical baryon spectrum is in accordance with the experimental results in both intrinsic quantum numbers and masses. These results show that various baryons are the energy band excited states of the Lee Particles. We also predict some new baryons: $\Lambda^0(2559)$, $\Lambda^0(4279)$, $\Xi_C(3169)$, $\Omega^-(3619)$, $\Lambda_C^+(6659)$, $\Lambda_b^0(10159)$... Furthermore, from the electromagnetic interaction periodic field of the vacuum material, we predict a super heavy electron spectrum $E(166\ \text{Gev})$, $E(332\ \text{Gev})$, $E(498\ \text{Gev})$... We suggest that experiments to find the super heavy electron spectrum and long lifetime baryon $\Lambda^0(2559)$ should be done.

I Introduction

The Quark Model [1] has already explained the baryon spectrum in terms of the quarks. It successfully gives intrinsic quantum numbers (the isospin I, the strange number S, the charmed number C, the bottom number b, the electric charge Q) of all baryons. However, (1) it has not given a satisfactory mass spectrum of baryons in a united mass formula [2]; (2) it needs too many elementary particles (6 flavors $\times$ 3 colors $\times$ 2 (quark and antiquark) = 36 quarks) [3] [4]; (3) the intrinsic quantum numbers of the quarks are "entered by hand" [5] [6]; (4) on the one hand it assumes [1] that all quarks (u, d, s, c, b, t) are independent elementary particles, but on the other hand it assumes that the higher energy quarks can decay into lower energy quarks [7], the two "hands" do not cooperate with each other; (5) all free quark searches since 1977 have had negative results [8]. This paper will try to find a possible solution to the above problems of the Quark Model.

According to the confinement idea [9], quarks are confined inside hadrons. The question is, are quarks also confined inside hadrons when they are in the vacuum state? The fact that free quarks have not yet been found may imply that the quarks are confined in the vacuum state. We also think that **the (Quark Model's) assumption that all quarks (u, d, s, c, b, t) are independent elementary particles has already blocked the correct way to find a united mass formula of the baryons.** Considering the fact [10] that all higher energy baryons decay into lower energy baryons and finally decay into nucleons, we guess that (1) there are only two kinds of the elementary quarks (u and d) in the vacuum; (2) they have already formed two colorless quark groups uud and udd (we call the colorless quark groups uud and udd **the Lee Particles** [11] [12] [13]) in the vacuum; (3) the above facts (all higher energy baryons decay into lower energy baryons and finally decay into nucleons) may indicate that **all baryons may be the same kind of particles (the Lee Particles) in different states with different**

energy and quantum numbers; (4) the strange number S, the charmed number C, and the bottom number b reflect some symmetry properties of the different states of the Lee Particles rather than coming from new quarks (s, c, b). Now we need a mechanism which can generate the baryon spectrum–various states (with different properties and masses) of the Lee Particles.

Twenty years ago, T. D. Lee had already noticed that [5] : "the standard model... needs ~ 20 parameters: e, G, θ_w,various masses for the three generations of leptons and quarks and the four weak decay angles $\theta_1, \theta_2, \theta_3$,and δ." "Therefore, while we may have achieved a rather effective description of physical processes up to about 100 Gev, the theory we have should more appropriately be viewed as essentially phenomenological. After all, who has ever heard of a fundamental theory that requires twenty - some parameters?" He then suggested some possible directions that "may change our present frame of thinking": "1. Size of leptons and quarks." "2. Possibility of vacuum engineering." "3. Improvement on conventional quantum mechanics." Furthermore, in the section which discussed the possibility of vacuum engineering, T. D. Lee pointed out: "we believe our vacuum, though Lorentz invariant, to be quite complicated. Like any other physical medium, it can carry long-range-order parameters and it may also undergo phase transitions... If we can create vacuum excitations or vacuum phase transitions, then any of the constants in our present theory, $\theta_w, \theta_c, m_u, m_d$,... , can be subject to change."

Recently Frank Wilczek, the J. Robert Oppenheimer Professor at the Institute for Advanced Study in Princeton, further elaborated Lee's idea [14]: "empty space–the vacuum–is in reality a richly structured, though highly symmetrical, medium. Dirac's sea was an early indication of this feature, which is deeply embedded in quantum field theory and the Standard Model. Because the vacuum is a complicated material governed by locality and symmetry, one can learn how to analyze it by studying other such materials–that is, condensed matter." Professor Wilczek not only pointed out one of

the most important and most urgent research directions of modern physics–studying the structure of the vacuum, but also provided a very practical and efficient way for the studying–learning from studying condensed matter.

Applying the Lee-Wilczek idea, this paper conjectures a structure of the vacuum (body center cubic symmetry), which will be used as the mechanism to generate the baryon spectrum (various excited states of the Lee Particles). This paper will deduce the intrinsic quantum numbers (including S, C, and b) and the masses of all baryons in terms of a phenomenological model (the BCC model), using only the u quarks and the d quarks. The BCC model will show that although baryons (Δ, N, Λ, Σ, Ξ, Ω, Λ_C, Ξ_C, Σ_C, and Λ_C) are so different from one another in I, S, C, b, Q, and M, they are the same kind of particles (the Lee Particles) which are in different energy band states. The theoretical results of the BCC model on the intrinsic numbers and masses of baryons are in good agreement with the experimental results. The BCC model also predicts a super heavy electron spectrum. The super heavy electron spectrum may be a touchstone of the model of the vacuum medium.

According to Dirac's sea concept [15], there are electron Dirac sea, μ lepton Dirac sea, τ lepton Dirac sea, u quark Dirac sea, d quark Dirac sea, s quark Dirac sea, c quark Dirac sea, b quark Dirac sea...in the vacuum. All of these Dirac seas are in the same space, at any location, that is, at any physical space point. According to the Quark Model and the quantum chromodynamics [16], there are super-strong color attractive interactions among the quarks, causing three quarks of different colors to be confined together and form a colorless baryon (p, n, Λ, Σ, Ξ, Ω..). These baryons, electrons, leptons, etc. will interact with one another and form the perfect vacuum material. However, some kinds of particles do not play an important role in forming the vacuum material. First, the main force which makes and holds the structure of the vacuum material must be the strong interactions, not the weak-electromagnetic, or the gravitational interactions. Hence, in considering the structure of the vacuum material, we leave out the Dirac seas

of those particles which do not have strong interactions (e, μ, τ). Secondly, it is unlikely that the super stable vacuum material is composed of unstable blocks, hence we also omit the unstable particles (such as: Λ, Σ, Ξ, Ω, ...). Finally, there are only two kinds of possible particles left: the vacuum state protons (uud-Lee Particle) and the vacuum state neutrons (udd-Lee Particle). It is well known that there are strong attractive forces between the protons and the neutrons inside a nucleus. Similarly, there should also exist the strong attractive forces between the Lee Particles (uud) and the Lee Particles (udd) which will make and hold the densest structure of the vacuum state Lee Particles.

According to solid state physics [17], if two kinds of particles (with radius $R_1 < R_2$) satisfy the condition $1 > R_1/R_2 > 0.73$, the densest structure is the body center cubic crystal [18]. We know: first, the Lee Particle (uud) and the Lee Particle (udd) are not completely the same, thus $R_1 \neq R_2$; second, they are similar to each other (they have the same $S = C = b = 0$, and their first excited states have essentially the same masses: $M_{uud} = 938.3$ Mev, $M_{udd} = 939.6$ Mev), thus $R_1 \approx R_2$. Hence, if $R_1 < R_2$ (or $R_2 < R_1$), we have $1 > R_1/R_2 > 0.73$ (or $1 > R_2/R_1 > 0.73$). Therefore, we conjecture that the vacuum state Lee Particles construct the densest structure which is the body center cubic lattice (in this paper it will be regarded as **the BCC model**). At the same time, the vacuum Lee Particles (uud) alone forms a simple cubic lattice. In addition, there should be a vacuum electron (with the electric charge -1) in each body center cubic cell to preserve electric neutrality, because there is a vacuum Lee Particle (uud) (with the positive electric charge $+1$) in the cubic cell.

Similar to a crystal, which has a periodic field, there are also periodic fields in the vacuum. Particularly, there will be two kinds of periodic fields: the periodic field with the body center cubic symmetries is a strong interaction field; the other with the simple cubic symmetries of vacuum state protons is an electromagnetic interaction field.

For the strong interaction periodic field, from energy band theory [19] and the phenomenological fundamental hypotheses of the BCC model, we can deduce all intrinsic

quantum numbers of all baryons (the isospin I, the strange number S, the charmed number C, the bottom number b, the electric charge Q) which are consistent with the experimental results [10]. Likewise, we can calculate the masses of all baryons which are in very good agreement with the experimental results [10], using a united mass formula.

Similarly, from the simple cubic electromagnetic periodic field, we get a super heavy electron spectrum. Super heavy electrons are so heavy that even the lightest one is about 177 times heavier than a proton. So far none of the super heavy electrons has been confirmed by the experiments completely. However, the interesting thing is that a heavy particle of approximately 177 times heavier than a proton has already been discovered [20].

We should note that an ideal crystal does not scatter particles. Because the Hamiltonian of a particle in the ideal crystal is independent of time, the particle is in a stationary state. If there is no perturbation, the particle will remain in the state forever. Thus, as a property of the body center cubic symmetric structure, the vacuum material should not scatter particles as well. The vacuum material is like an ultra-superconductor. Just as electrons can move inside superconductors without encountering electric resistance, any particle can move inside the ultra-superconductor (vacuum material) not only without encountering electric resistance, but also without encountering mechanical resistance.

The structure of the vacuum material may help us understand many fundamental problems. For example, the periodic field of the vacuum material may lead to an explanation for the particle-wave duality in quantum mechanics; the vacuum material may be the source of asymmetry [12]; a broken hole of the perfect vacuum material may help us explain the black hole...

This paper is organized as follows: The fundamental hypotheses are presented in *Section II*. The motion equation is solved with a free particle approximation [21] in *Section III*. The recognition of baryons is accomplished in *Section IV*. A comparison of the results of the BCC model and the experimental results is listed in *Section V*. The pre-

dictions of the model (including the super-heavy electron spectrum), recommendations for experimental tests, and discussions are stated in *SectionVI*. The conclusions are in *SectionVII*.

II Fundamental Hypotheses

The BCC model attempts to explain the spectrum of baryons in terms of the outside environment. For simplicity, the intrinsic structure (three quarks) of baryons will be ignored temporarily while the outside influences of the vacuum is being considered. In other words, the baryons are treated as elementary particles without intrinsic structure in the phenomenological BCC model. We would like to call this simplification **the point baryon approximation**. We will call **the point approximations of the colorless quark group uud and udd as the Lee Particles (uud - charged Lee Particle, udd - neutral Lee Particle).** The approximation is based on the the quark confinement theory [9] and the experimental results [8] that a baryon always appears as a whole particle. Indeed, we have never seen a part of a baryon alone in any experiment. By ignoring the intrinsic structure of baryons, we can focus our attention on the outside influence.

In order to explain our model accurately and concisely, we will start from the phenomenological fundamental hypotheses in an axiomatic form.

Hypothesis I *There are only two kinds of fundamental quarks u and d in the quark family. There exist super-strong color attractive interactions between the colored quarks. Three quarks (uud or udd) compose a kind of colorless Fermi particles in the vacuum state.*

According to the Quark Model [1], above Fermi particles (the Lee Particles) are unflavored ($S = C = b = 0$) with spin $s = 1/2$ and isotropic spin $I = 1/2$. From the

quantum field theory [22], a Lee Particle serves only as the background for the physical vacuum (the baryon number $B = 0$) when it is in the vacuum state. However, once it is excited from the vacuum, it becomes an observable particle ($B = 1$, $S = C = b = 0$, $s = 1/2$, and $I = 1/2$). Generally, the excited Lee Particles ($B = 1$, $S = C = b = 0$) with the third component of the isospin $I_z = +1/2$ are protons, and with the third component of the isospin $I_z = -1/2$ are neutrons.

Hypothesis II *There are strong attractive interactions between the Lee Particles, the interactions will make and hold the densest structure of the Lee Particles - the body center cubic Lee Particle Lattice in the vacuum. The lattice forms a strong interaction periodic field with body center cubic symmetries in the vacuum, where the periodic constant a_x is much smaller than the magnitude of the radii of the nuclei.*

Hypothesis III *Quantum mechanics applies to the ultra-microscopic world [23]. Thus, the energy band theory [19] is also valid in the ultra-microscopic world.*

According to the energy band theory, an excited Lee Particle (from vacuum), inside the body center cubic periodic field, will be in a state of the energy bands. **The energy band excited states of the Lee Particles will be various baryons**. According to the point baryon approximation, we will treat the Lee Particle as a point particle without intrinsic structure in this paper..

Hypothesis IV *Due to the effect of the periodic field, fluctuations of an excited Lee Particle state may exist. Thus, the fluctuations of energy ε and intrinsic quantum numbers (such as the strange number S) may exist also. The fluctuation of the Strange number, if exists, is always $\Delta S = \pm 1$ [24]. From the fluctuation of the Strange number we will be able to deduce new quantum numbers, such as the Charmed number C and the Bottom number b.*

Hypothesis V *The energy band excited states (except the energy bands in the first Brillouin zone) of the Lee Particles are unstable baryons (we call all baryons except protons and neutrons unstable baryons). Their quantum numbers and masses are determined as follows (note: the quantum numbers of the ground energy bands in the first Brillouin zone are determind by* ***Hypothesis I):***

1. Baryon number B: according to **Hypothesis I**, all energy band states have

$$B = 1. \tag{1}$$

2. The ground energy bands (in the firs Brillouin zone) are the free excited states of the Lee Particles. They have I =1/2, S = C = b =0, from **Hypothesis I. In other words, they are** nucleons.

3. Isospin number I: the maximum isospin I_m is determined by the energy band degeneracy d [19], where

$$d = 2I_m + 1, \tag{2}$$

and another possible isospin value is determined by

$$I = I_m - 1, \quad I \geq 0. \tag{3}$$

4. Strange number S: the Strange number S is determined by the rotary fold R of the symmetry axis [19] with

$$S = R - 4, \tag{4}$$

where the number 4 is the highest possible rotary fold number.

5. Electric charge Q: after obtaining B, S and I, we can find the charge Q from the Gell-Mann-Nishijiman relationship [25]:

$$Q = I_z + 1/2(S + B). \tag{5}$$

6. Charmed number C and Bottom number b: Since the Lee Particles do not have any partial charge and the unstable baryons are the energy band excited states of the Lee Particles, the unstable baryons shall not have partial charges. Thus, if a partial charge is resulted from (4) and (5), (4) will be changed into

$$\bar{S} = R - 4. \tag{6}$$

From **Hypothesis IV ($\Delta S = \pm 1$),** the real value of S is

$$S = \bar{S} + \Delta S = (R - 4) \pm 1. \tag{7}$$

The "Strange number" S in (7) is not completely the same as the strange number in (4). In order to compare it with the experimental results, we would like to give it a new name under certain circumstances. Based on **Hypothesis IV**, the new names will be the **Charmed** number and the **Bottom** number:

if $S = +1$ which originates from the fluctuation $\Delta S = +1$,
then we call it the **Charmed** number C ($C = +1$); (8)

if $S = -1$ which originates from the fluctuation $\Delta S = +1$,
and if there is an energy fluctuation,
then we call it the **Bottom** number b ($b = -1$). (9)

Thus, (5) needs to be generalized to

$$Q = I_z + 1/2(B + S_G) = I_z + 1/2(B + S + C + b), \tag{10}$$

where we define the generalized strange number as

$$S_G = S + C + b. \tag{11}$$

7. Charmed strange baryon Ξ_C and Ω_C: if the energy band degeneracy d is larger than the rotary fold R, the degeneracy will be divided. Sometimes degeneracies should be divided more than once. After the first division, the sub-degeneracy energy bands have $S_{Sub} = \bar{S} + \Delta S$. For the second division of a degeneracy bands, we have:

$$\begin{aligned} &\text{if the second division has fluctuation } \Delta S = +1, \\ &\text{then } S_{Sub} \text{ may be unchanged and we may have} \\ &\text{a Charmed number } C \text{ from } C = \Delta S = +1. \end{aligned} \tag{12}$$

Therefore, we can obtain charmed strange baryons Ξ_C and Ω_C.

8. We assume that a baryon's static mass is the minimum energy of the energy curved surface which represents the baryon.

III The Energy Bands

A The Motion Equation of the Lee Particle

When a Lee Particle is excited from vacuum, it becomes an observable physical particle. Since the Lee Particle is a Fermion, its motion equation should be the Dirac equation. Taking into account that (according to the renormalization theory [26]) the bare mass of the Lee Particle is much larger than the empirical values of the baryon masses, we use the Schrödinger equation instead of the Dirac equation (our results will show that this is a very good approximation):

$$\frac{\hbar^2}{2m_b}\nabla^2\Psi + (\varepsilon - V(\vec{r}))\Psi = 0, \tag{13}$$

where $V(\vec{r})$ denotes the strong interaction periodic field with body center cubic symmetries and m_b is the bare mass of the Lee Particle.

B Finding the Energy Bands

Using the energy band theory [19] and the free particle approximation [21] (taking $V(\vec{r}) = V_0$ constant and making the wave functions satisfy the body center cubic periodic symmetries), we have

$$\frac{\hbar^2}{2m_b}\nabla^2\Psi + (\varepsilon - V_0)\Psi = 0, \tag{14}$$

where V_0 is a constant potential. The solution of Eq.(14) is a plane wave

$$\Psi_{\vec{k}}(\vec{r}) = \exp\{-i(2\pi/a_x)[(n_1 - \xi)x + (n_2 - \eta)y + (n_3 - \zeta)z]\}, \tag{15}$$

where the wave vector $\vec{k} = (2\pi/a_x)(\xi, \eta, \zeta)$, a_x is the periodic constant, and n_1, n_2, n_3 are integers satisfying the condition

$$n_1 + n_2 + n_3 = \pm \text{ even number or } 0. \tag{16}$$

Condition (16) implies that the vector $\vec{n} = (n_1, n_2, n_3)$ can only take certain values. For example, $\vec{n}$ can not take $(0, 0, 1)$ or $(1, 1, -1)$, but can take $(0, 0, 2)$ and $(1, -1, 2)$.

The zeroth-order approximation of the energy [21] is

$$\varepsilon^{(0)}(\vec{k}, \vec{n}) = V_0 + \alpha E(\vec{k}, \vec{n}), \tag{17}$$

$$\alpha = h^2/2m_b a_x^2, \tag{18}$$

$$E(\vec{k}, \vec{n}) = (n_1 - \xi)^2 + (n_2 - \eta)^2 + (n_3 - \zeta)^2. \tag{19}$$

Now we will demonstrate how to find the energy bands.

The first Brillouin zone [27] of the body center cubic lattice is shown in Fig. 1. In Fig. 1 (depicted from [19] (Fig. 1) and [27](Fig. 8.10)), the (ξ, η, ζ) coordinates of the symmetry points are:

$$\Gamma = (0,\ 0,\ 0),\ H = (0,\ 0,\ 1),\ P = (1/2,\ 1/2,\ 1/2),$$
$$N = (1/2,\ 1/2,\ 0),\ M = (1,\ 0,\ 0), \tag{20}$$

and the (ξ, η, ζ) coordinates of the symmetry axes are:

$$\begin{aligned}
\Delta &= (0,\, 0,\, \zeta),\ 0 < \zeta < 1; \qquad \Lambda = (\xi,\, \xi,\, \xi),\ 0 < \xi < 1/2; \\
\Sigma &= (\xi,\, \xi,\, 0),\ 0 < \xi < 1/2; \qquad D = (1/2,\, 1/2,\, \xi),\ 0 < \xi < 1/2; \\
G &= (\xi,\, 1\text{-}\xi,\, 0),\ 1/2 < \xi < 1; \quad F = (\xi,\, \xi,\, 1\text{-}\xi),\ 0 < \xi < 1/2.
\end{aligned} \tag{21}$$

For any valid value of the vector $\vec{n}$, substituting the (ξ, η, ζ) coordinates of the symmetry points or the symmetry axes into Eq.(19) and Eq.(15), we can get the $E(\vec{k}, \vec{n})$ values and the wave functions at the symmetry points and on the symmetry axes. In order to show how to calculate the energy bands, we give the calculation of some low energy bands in the symmetry axis Δ as an example (the results are illustrated in Fig. 2(a)).

First, from (19) and (15) we find the formulas for the $E(\vec{k}, \vec{n})$ values and the wave functions at the end points Γ and H of the symmetry axis Δ, as well as on the symmetry axis Δ itself:

$$E_\Gamma = n_1^2 + n_2^2 + n_3^2, \tag{22}$$

$$\Psi_\Gamma = \exp\{-i(2\pi/a_x)[n_1 x + n_2 y + n_3 z]\}. \tag{23}$$

$$E_H = n_1^2 + n_2^2 + (n_3 - 1)^2, \tag{24}$$

$$\Psi_H = \exp\{-i(2\pi/a_x)[n_1 x + n_2 y + (n_3 - 1) z]\}. \tag{25}$$

$$E_\Delta = n_1^2 + n_2^2 + (n_3 - \zeta)^2, \tag{26}$$

$$\Psi_\Delta = \exp\{-i(2\pi/a_x)[n_1 x + n_2 y + (n_3 - \zeta) z]\}. \tag{27}$$

Then, using (22)–(27), beginning from the lowest possible energy, we can obtain the corresponding integer vectors $\vec{n} = (n_1, n_2, n_3)$ (satisfying (16)) and the wave functions:

1. The lowest $E(\vec{k},\vec{n})$ is at $(\xi,\eta,\zeta)=0$ (the point Γ) and with only one value of $\vec{n}=(0,0,0)$ (see (22) and (23)):

$$\vec{n}=(0,\,0,\,0)\qquad E_\Gamma=0\qquad \Psi_\Gamma=1. \tag{28}$$

2. Starting from $E_\Gamma=0$, along the axis Δ, there is one energy band (the lowest energy band $E_\Delta=\zeta^2$, with $n_1=n_2=n_3=0$ (see (26) and (27)) ended at the point $E_H=1$:

$$\vec{n}=(0,\,0,\,0),\qquad E_\Gamma=0\rightarrow E_\Delta=\zeta^2\rightarrow E_H=1,$$
$$\Psi_\Delta=\exp[i(2\pi/a_x)(\zeta z)]. \tag{29}$$

3. At the end point H of the energy band $E_\Gamma=0\rightarrow E_\Delta=\zeta^2\rightarrow E_H=1$, the energy $E_H=1$. Also at the point H, $E_H=1$ when $n=(\pm1,0,1)$, $(0,\pm1,1)$, and $(0,0,2)$ (see (24) and (25)):

$$E_H=1,\quad \Psi_H=[e^{[i(2\pi/a_x)(\pm x)]},e^{[i(2\pi/a_x)(\pm y)]},e^{[i(2\pi/a_x)(\pm z)]}]. \tag{30}$$

4. Starting from $E_H=1$, along the axis Δ, there are three energy bands ended at the points $E_\Gamma=0$, $E_\Gamma=2$, and $E_\Gamma=4$, respectively:

$$\vec{n}=(0,0,0),\quad E_H=1\rightarrow E_\Delta=\zeta^2\rightarrow E_\Gamma=0,$$
$$\Psi_\Delta=\exp[i(2\pi/a_x)(\zeta z)]. \tag{31}$$

$$\vec{n}=(0,0,2),\quad E_H=1\rightarrow E_\Delta=(2\text{-}\zeta)^2\rightarrow E_\Gamma=4,$$
$$\Psi_\Delta=\exp\,[i(2\pi/a_x)(2-\zeta)z)]. \tag{32}$$

$$\vec{n}=(\pm1,0,1)(0,\pm\,1,1),\quad E_H=1\rightarrow E_\Delta=1+(1\text{-}\zeta)^2\rightarrow E_\Gamma=2,$$
$$\Psi_\Delta=e^{\{-i(2\pi/a_x)[\pm x+(1-\zeta)z]\}},e^{\{-i(2\pi/a_x)[\pm y+(1-\zeta)z]\}}. \tag{33}$$

The energy band ($E_H=1\rightarrow E_\Delta=1+(1\text{-}\zeta)^2\rightarrow E_\Gamma=2$) is a 4 fold degeneracy band.

5. The energy bands with 4 sets of values $\vec{n}$ ($\vec{n}$ = (±1,0,1), (0,±1,1)) ended at $E_\Gamma = 2$. From (22), $E_\Gamma = 2$ also when $\vec{n}$ takes other 8 sets of values: $\vec{n} = (1, \pm 1, 0)$, $(-1, \pm 1, 0)$, and $(\pm 1, 0, -1)$, $(0, \pm 1, -1)$. Putting the 12 sets of $\vec{n}$ values into Eq. (23), we can obtain 12 plane wave functions:

$$E_\Gamma = 2,\ \Psi_\Gamma = [e^{i(2\pi/a_x)(\pm x \pm y)}, e^{i(2\pi/a_x)(\pm y \pm z)}, e^{i(2\pi/a_x)(\pm z \pm x)}]. \tag{34}$$

6. Starting from $E_\Gamma = 2$, along the axis Δ, there are three 4 fold degeneracy energy bands ended at the points $E_H = 1$, $E_H = 3$, and $E_H = 5$, respectively:

$$\vec{n} = (\pm 1,0,1)(0, \pm 1,1),\ E_\Gamma = 2 \rightarrow E_\Delta = 1+(1\text{-}\zeta)^2 \rightarrow E_H = 1, \tag{35}$$

$$\vec{n} = (1, \pm 1,0)(\text{-}1, \pm 1,0),\ E_\Gamma = 2 \rightarrow E_\Delta = 2+\zeta^2 \rightarrow E_H = 3, \tag{36}$$

$$\vec{n} = (\pm 1,0,\text{-}1)(0, \pm 1,\text{-}1),\ E_\Gamma = 2 \rightarrow E_\Delta = 1+(\zeta+1)^2 \rightarrow E_H = 5. \tag{37}$$

Continuing the process, we can find all the energy bands and the corresponding wave functions. The wave functions are not needed for the zeroth order approximation, so we only show the energy bands in Fig. 2-5. There are six small figures in Fig. 2-4. Each of them shows the energy bands in one of the six axes in Fig. 1. Each small figure is a schematic one where the straight lines that show the energy bands shold be parabolic curves. The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the energy bands with the same energy (the zeroth order approximation). The numbers beside both ends of an energy band (the intersection of the energy band line and the vertical lines) represent the highest and lowest E($\vec{k}$,$\vec{n}$) values (see Eq. (19)) of the band. Putting the values of the E($\vec{k}$,$\vec{n}$) into Eq. (17), we get the zeroth order energy approximation values (in Mev).

IV The Recognition of the Baryons

It is worth while to emphasize that **there are significant differences between nucleons (proton, neutron) and unstable baryons** (Δ, N, Λ, Σ, Ξ, Ω, Λ_C, Ξ_C, Σ_C, Λ_b...) **in the BCC model**. According to **Hypothesis I**, the excited Lee Particles with the third component of the isospin $I_z = +1/2$ are protons, and the excited Lee Particles with the third component of the isospin $I_z = -1/2$ are neutrons. On the other hand, the unstable baryons are the energy band excited states of the Lee Particles. Their intrinsic quantum numbers and masses can be found using **Hypothesis V** and (17)**.** However, they are excited from the same particles-the Lee Particles. The nucleons are the ground bands. Therefore, we can determine V_0 in formula (17), using the static masses (static energy) $M_{nucleon}$ of the nucleons. The static energy ($M_{nucleon} = 939$ Mev ([10])) of the nucleons should be the lowest energy (V_0) of the energy bands in (17). Thus, at the ground states, we have

$$\varepsilon^{(0)} = V_0 = M_{nucleon} = 939 \text{ Mev}. \tag{38}$$

Fitting the theoretical mass spectrum to the empirical mass spectrum of the baryons, we can also determine

$$\alpha = h^2/2m_b a_x^2 = 360 \text{ Mev} \tag{39}$$

in (17). Thus, we have

$$\varepsilon^{(0)}(\vec{k}, \vec{n}) = V_0 + \alpha E(\vec{k}, \vec{n}) = 939 + 360E(\vec{k}, \vec{n}) \quad \text{(Mev)}. \tag{40}$$

If there were no strong interaction periodic field, we would only see protons and neutrons as excited free Lee Particles ($N(939)$). We could not see any other baryons because they would not exist. Due to the periodic field, although protons and neutrons are still the essential state of the excited Lee Particles, there is a slight chance that the Lee Particles are excited to **the symmetry points** (see Fig. 1) of the periodic field.

Once at the symmetry points, the Lee Particles will show special symmetric properties. Due to the periodic field, the parabolic energy curve of the free Lee Particle will be changed to energy bands (see Eq. (17) and Fig. 2-5). Also, there will be energy **gaps** on the surfaces of the Brillouin zones which originate from the periodic field. **The symmetry points** and **the energy gaps** will give the excited Lee Particles some special properties and longer lives, which are different from those of the free nucleons ($N(939)$) with the same energy. Because of these properties, physicists naturally regard them as new baryons that are different from protons and neutrons.

Using **Hypothesis V** and the energy bands (Fig. 2-5), we can find the quantum numbers and masses of all excited energy bands. Then, from the quantum numbers and the masses we can recognize the **unstable baryons**.

About the quantum numbers, considering the energy bands, we have:

1. All energy band states have the baryon number $B = 1$ from (1).

2. All energy bands with $\vec{n} = (0,0,0)$ (in the first Brillouin zone) have $S = C = b = 0$, spin s =1/2, and I=1/2 from **Hypothesis I**. They represent the baryon N(939) from (38).

$$\vec{n} = (0,0,0) \quad \text{S=C=b=0} \quad \text{I =1/2} \quad \text{s =1/2} \quad \text{N(939)}. \tag{41}$$

3. Except for the first Brillouin zone, the isospin I is determined by (2) and (3). In some cases the degeneracy d should be divided into sub-degeneracies before using the formulas. Specifically, if the degeneracy d is larger than the rotary fold R of the symmetry axis:

$$d > R, \tag{42}$$

then we assume that the degeneracy will be divided into γ sub-degeneracies, where

$$\gamma = d/R. \tag{43}$$

For the three axes which pass through the center point Γ (the axis $\Delta(\Gamma - H)$, the axis $\Lambda(\Gamma - P)$, the axis $\Sigma(\Gamma - N)$), the energy bands in the same degeneracy group have symmetric $\vec{n}$ ($\vec{n} = (n_1, n_2, n_3)$) values (see Fig. 2(a), 2(b) and 3(a)). Hence, if the sub-degeneracy $d_{sub} \leq R$, it will not be divided further. About "symmetric" $\vec{n}$, we give a definition: **A group of $\vec{n} = (n_1, n_2, n_3)$ values is said to be symmetric if any two $\vec{n}$ values in the group can transform to each other by various permutation (change component order) and changing the sign "$\pm$" (multiplied by "-1") of the components (one, two, or all three).** For example, $(-2, -1, 3)$ and $(-3, 2, 1)$ are symmetric, but $(-3, 0, 2)$ and $(-3, 0, 1)$ are asymmetric.

For other three symmetry axes which are on the surface of the first Brillouin zone (the axis $D(P - N)$, the axis $F(P - H)$, the axis $G(M - N)$), the energy bands in the same degeneracy group may have asymmetric $\vec{n}$ values (see Fig. 3(b), 4(a) and 4(b)). This may indicate that they belong to different Brillouin zones. In such cases, even if a sub-degeneracy $d_{sub} \leq R$, it may still be divided further. Finding the criteria for dividing the degeneracy depends on the structures of the Brillouin zones, the irreducible representations of the single and double point groups [28], and requires a higher order approximation. Hence, it is beyond the scope of this paper. In order to simplify, we assume (some phenomenological rules) that (a) the degeneracy of the energy bands which are in the first and second Brillouin zones will be divided. (b) if $\Delta\varepsilon \neq 0$ (see (55)), an asymmetric sub-degeneracy should be divided at the end point N (the lowest symmetry point, only has 8 symmetric operations [29]); may or may not be divided at end point P (24 symmetric operations [29]) with a possibility of 50% ; but should not be divided at the end points H and M (the highest symmetry points, 48 symmetric

operations [29]):

$$\begin{aligned} &\text{if } \Delta\varepsilon \neq 0, \text{ divided at end point } N; \\ &\text{not divided at end points } H \text{ and } M; \\ &\text{divided at end point } P \text{ with possibility of } 50\%. \end{aligned} \tag{44}$$

However, if $\Delta\varepsilon = 0$, the asymmetric sub-degeneracy should not be divided. After finding the sub-degeneracy d_{sub}, we can use (2) (d_{sub} = 2I+1) to find the isospin I.

4. Except for the first Brillouin zone, the strange number S is determined by (4), where the number 4 is the highest rotary fold number (R) of the highest rotary symmetry axis. To be specific, from Eq. (4) and Fig. 1, we get

$$\Delta(\Gamma - H) \text{ is a 4-fold rotation axis, } R = 4 \rightarrow S = 0; \tag{45}$$

$$\Lambda(\Gamma - P) \text{ is a 3-fold rotation axis, } R = 3 \rightarrow S = -1; \tag{46}$$

$$\Sigma(\Gamma - N) \text{ is a 2-fold rotation axis, } R = 2 \rightarrow S = -2. \tag{47}$$

For the other three symmetry axes $D(P - N)$, $F(P - H)$, and $G(M - N)$, which are on the surface of the first Brillouin zone (see Fig. 1), we determine the strange numbers as follows:

$$D(P - N) \text{ is parallel to axis } \Delta, \; S_D = S_\Delta = 0; \tag{48}$$

$$F \text{ is parallel to an axis equivalent to } \Lambda, \; S_F = S_\Lambda = -1; \tag{49}$$

$$G \text{ is parallel to an axis equivalent to } \Sigma, \; S_G = S_\Sigma = -2. \tag{50}$$

5. Except for the first Brillouin zone, other quantum numbers will also be determind by **Hypothesis V**.

6. When the energy is low, the baryons from different axes in the same Brillouin zone, and with the same S, C, b, Q, I, I_Z, and $\overrightarrow{n}$ values, are ragarded as the same baryon. The mass of the baryon is the lowest value of their energy curved surface. For example, in the second Brillouin zone, the energy bands (on diffrent symmetry axes) with n = (1, 1, 0) are the same band (the same energy curved surface in the three dimensional phase space). They have the same quantum numbers ($S = -1, C = b = Q = I = I_Z = 0$). The lowest energy is 1119 - the baryon $\Lambda(1119)$.

Starting from the axis $\Delta(\Gamma - H)$, we recognize the **unstable baryons**.

A The Axis $\Delta(\Gamma - H)$

The axis $\Delta(\Gamma - H)$ is a 4 fold rotary symmetry axis, $R = 4$. From (45), we get the strange number $S = 0$. For low energy levels, there are 8 and 4 fold degenerate energy bands and single bands on the axis. Since the axis has $R = 4$, from (42) and (43), the energy bands of degeneracy 8 will be divided into two 4 fold degenerate bands.

A- 1 The four fold degenerate bands on the axis $\Delta(\Gamma - H)$

For the 4 fold degenerate bands (see Fig. 2(a) and Fig. 5(a)), using (2), we get the isospin $I_m = 3/2$, and using (5), we have $Q = 2,\ 1,\ 0,\ -1$. Comparing them with the experimental results [10] that the baryon families $\Delta(\Delta^{++}, \Delta^{+}, \Delta^{0}, \Delta^{-})$ have $S = 0$, $I = 3/2$, $Q = 2,\ 1,\ 0,\ -1$, we discover that each four fold degenerate band represents a baryon family Δ. Using (3), we get another $I = 3/2 - 1 = 1/2$, and from (5), we get $Q = 1,\ 0$. From the facts [10] that the baryon families $N(N^{+}, N^{0})$ have $S = 0$, $I = 1/2$, and $Q = 1,\ 0$, we know that there is another baryon family N corresponding to each Δ

family. Using Fig. 2(a) and Fig. 5(a), we can get E_Γ, E_H, and $\vec{n}$ values. Then, putting the values of the E_Γ and E_H into the energy formula (40), we can find the values of the energy $\varepsilon^{(0)}$. Finally, we have

$$\begin{array}{llll}
E_H = 1 & \vec{n} = (101,\text{-}101,011,0\text{-}11) & \varepsilon^{(0)} = 1299 & \Delta(1299);\ N(1299) \\
E_\Gamma = 2 & \vec{n} = (110,1\text{-}10,\text{-}110,\text{-}1\text{-}10) & \varepsilon^{(0)} = 1659 & \Delta(1659);\ N(1659) \\
E_\Gamma = 2 & \vec{n} = (10\text{-}1,\text{-}10\text{-}1,01\text{-}1,0\text{-}1\text{-}1) & \varepsilon^{(0)} = 1659 & \Delta(1659);\ N(1659) \\
E_H = 3 & \vec{n} = (112,1\text{-}12,\text{-}112,\text{-}1\text{-}12) & \varepsilon^{(0)} = 2019 & \Delta(2019);\ N(2019) \\
E_\Gamma = 4 & \vec{n} = (200,\text{-}200,020,0\text{-}20) & \varepsilon^{(0)} = 2379 & \Delta(2379);\ N(2379) \\
E_H = 5 & \vec{n} = (121,1\text{-}21,\text{-}121,\text{–}1\text{-}21, & \varepsilon^{(0)} = 2739 & \Delta(2739);\ N(2739) \\
 & \quad 211,2\text{-}11,\text{-}211,\text{-}2\text{-}11) & \varepsilon^{(0)} = 2739 & \Delta(2739);\ N(2739) \\
E_H = 5 & \vec{n} = (202,\text{-}202,022,0\text{-}22) & \varepsilon^{(0)} = 2739 & \Delta(2739);\ N(2739) \\
E_H = 5 & \vec{n} = (013,0\text{-}13,103,\text{-}103) & \varepsilon^{(0)} = 2739 & \Delta(2739);\ N(2739) \\
\ldots &&&
\end{array} \tag{51}$$

A- 2 The single bands on the axis $\Delta(\Gamma - H)$

From Fig. 2(a) and Fig. 5(b), we can see that there exist single bands on the axis Δ. From (2), we have $I = 0$. Using (4) and (5), we get $S = 0$ and $Q = 0 + 1/2(S + B) = 1/2$ (a partial charge). According to **Hypothesis V. 6**, we should use (7) instead of (4). Therefore, we have

$$S_{\text{Single}} = \bar{S}_\Delta \pm \Delta S = 0 \pm 1, \tag{52}$$

where $\Delta S = \pm 1$ from **Hypothesis IV**. The best way to guarantee the validity of Eq.(6) in any small region is to assume that ΔS takes $+1$ and -1 alternately from the lowest energy band to higher ones. In fact, the $\vec{n}$ values are really alternately taking positive and negative values: $E_H = 1$, $\vec{n} = (0, 0, 2)$; $E_\Gamma = 4$, $\vec{n} = (0, 0, -2)$; $E_H = 9$, $\vec{n} = (0, 0, 4)$; $E_\Gamma = 16$, $\vec{n} = (0, 0, -4)$; $E_H = 25$, $\vec{n} = (0, 0, 6)$; $E_\Gamma = 36$, $\vec{n} = (0, 0, -6)$ .... Using the fact, we can find a phenomenological formula. If we define a function $Sign(\vec{n})$

$$Sign(\vec{n}) = \frac{n_1 + n_2 + n_3}{|n_1| + |n_2| + |n_3|}\ , \tag{53}$$

then the **phenomenological formula is**

$$\Delta S = -(1 + S_{axis})Sign(\vec{n}). \tag{54}$$

For the single states on the axis Δ, we have $S_{axis} = 0$. Thue, from (54), we get

$$\Delta S = -(1 + S_{axis})Sign(\vec{n}) = -Sign(\vec{n}). \tag{54-A}$$

And for the single states on the axis Σ, since $S_{axis} = -2$, we have

$$\Delta S = -(1 + S_{axis})Sign(\vec{n}) = Sign(\vec{n}). \tag{54-B}$$

Before recognizing the baryons, we need to discuss the fluctuation of energy.

The fluctuation of the strange number will be accompanied by an energy change (**Hypothesis IV**). We assume that the change of the energy is proportional to (ΔS), a number $K \equiv 4 - R$ (R is the rotary number of the axis), and a number J representing the energy level with a **phenomenological formula:**

$$\Delta\varepsilon = \left\{ \begin{array}{cc} (-1)^K 100[(J-1) \times K - \delta(K)]\Delta S & J = 1,\, 2,\, ... \\ 0 & J = 0\ , \end{array} \right\} \tag{55}$$

where $\delta(K)$ is a Dirac function ($\delta(K) = 1$ when $K = 0$, and $\delta(K) = 0$ when $K \neq 0$.), and J is the energy level number ($J = 0, 1,\, 2,\, 3,...$) with asymmetric $\vec{n}$ values (or with partial electric charge from (4) for single energy bands) at the lowest point of the energy band. If the two end points of the axis have the same symmetries (such as the points Γ and H of the axis Δ), J will take 0, 1, 2 ... from the lowest energy band to the higher ones, no matter at which end point the lowest energy point is located (for example, see (60)). However, if the two end points of the axis have different symmetries (such as the points Γ and N of the axis Σ), J will take 0, 1, 2 ... from the lowest energy band to the higher ones for each of the two end points (for example, see (65)).

Applying (55) to the symmetry axes, we have:

for the axis Δ, $K = R - 4 = 0$,

$$\Delta\varepsilon = \left\{ \begin{array}{cc} -100 \times \Delta S & \text{J} = 1, 2, ..., \\ 0 & \text{J} = 0 \quad ; \end{array} \right\} \tag{56}$$

for the axes Λ and F, $K = 4 - R = 1$,

$$\Delta\varepsilon = \left\{ \begin{array}{cc} -100 \times (J-1)\Delta S & \text{J} = 1, 2, ..., \\ 0 & \text{J} = 0 \quad ; \end{array} \right\} \tag{57}$$

for the axes Σ, G, and D, $K = R - 4 = 2$

$$\Delta\varepsilon = \left\{ \begin{array}{cc} 200 \times (J-1)\Delta S & \text{J} = 1, 2, ..., \\ 0 & \text{J} = 0 \quad ; \end{array} \right\} \tag{58}$$

Due to the fluctuation, the energy formula (40) should be changed to

$$\begin{aligned} \varepsilon &= \varepsilon^{(0)}(\vec{\mathbf{k}}, \vec{\mathbf{n}}) + \Delta\varepsilon \\ &= \mathbf{939 + 360E}(\vec{\mathbf{k}}, \vec{\mathbf{n}}) + \Delta\varepsilon \quad . \end{aligned} \tag{59}$$

Formula (59) is the united mass formula which can give masses of all the baryons.

After obtaining the energy fluctuation formula, we come back to the study of the single bands on the axis Δ.

First, at $E_\Gamma = 0, J_\Gamma = 0$, $\Delta\varepsilon = 0$ from (56), the lowest energy band with $\vec{n} = (0, 0, 0)$ represents the baryon $N(939)$ from (41).

Then, we study the second lowest single energy band with $\vec{n} = (0, 0, 2)$ and $J = 1$. The lowest E of the band is at $E_H = 1$. From (54-A), $\Delta S = -Sign(\vec{n}) = -1$. Thus $S = \bar{S} + \Delta S = 0 + \Delta S = -1$, and $\Delta\varepsilon = 100$ Mev from (56)$\rightarrow$ the energy $\varepsilon = 939 + 360E + \Delta\varepsilon = 1399$ Mev from (59), as well as $I = Q = 0$ from (5). Therefore, it represents the baryon $\Lambda(1399)$.

For the third lowest band with $\vec{n} = (0, 0, -2)$, the lowest E of the band is at $E_\Gamma = 4$. Using (54-A), we get $\Delta S = +1$. Thus, $\mathbf{S} = \bar{\mathbf{S}}_\Delta + \mathbf{1} = \mathbf{1}$. The energy $\varepsilon = 939 + 360 \times 4 + \Delta\varepsilon = 2379 - 100 = 2279$ from (59) and (56). Here $S = +1$ originates from the fluctuation $\Delta S = +1$ and there is an energy fluctuation of $\Delta\varepsilon = -100$. From **Hypothesis V. 6 (8)**, we know the energy band has a charmed number $C = +1$. **It represents a new baryon with** $I = 0$, $C = +1$, and $Q = +1$. Since it has a charmed number $C = +1$, **we will call it the CHARMED baryon** $\Lambda_C^+(2279)$ [30]. It is very important to pay attention to **the Charmed baryon** $\Lambda_C^+(2279)$ **born here, on the single energy band, and from the fluctuation** $\Delta S = +1$ and $\Delta\varepsilon = -100$ Mev.

Continuing the above procedure, from Fig. 5 (b), (59), (54-A) and (56), we have (notice that the point H and the point Γ of the axis have the same symmetries):

$$
\begin{array}{lllllll}
E_H = 1 & \vec{n} = (002) & \Delta S = -1 & J = 1 & \Delta\varepsilon = +100 & \Lambda(1399) \\
E_\Gamma = 4 & \vec{n} = (00\text{-}2) & \Delta S = +1 & J = 2 & \Delta\varepsilon = -100 & \Lambda_C^+(2279) \\
E_H = 9 & \vec{n} = (004) & \Delta S = -1 & J = 3 & \Delta\varepsilon = +100 & \Lambda(4279) \\
E_\Gamma = 16 & \vec{n} = (00\text{-}4) & \Delta S = +1 & J = 4 & \Delta\varepsilon = -100 & \Lambda_C^+(6599) \\
E_H = 25 & \vec{n} = (006) & \Delta S = -1 & J = 5 & \Delta\varepsilon = +100 & \Lambda(10039) \\
E_\Gamma = 36 & \vec{n} = (00\text{-}6) & \Delta S = +1 & J = 6 & \Delta\varepsilon = -100 & \Lambda_C^+(13799) \\
\ldots &&&&&
\end{array}
\tag{60}
$$

B The Axis $\Lambda(\Gamma - P)$

The axis $\Lambda(\Gamma - P)$ is a 3 fold rotary symmetry axis, $R = 3$ and $S = -1$ from (46). From Fig. 2(b), we see that there is a single energy band with $\vec{n} = (0, 0, 0)$, and all other bands are 3 fold degenerate energy bands ($d = 3$) and 6 fold degenerate bands ($d = 6$).

At $E_\Gamma = 0$, $J_\Gamma = 0$, $\Delta\varepsilon = 0$ from (57), **the energy band with** $\vec{n} = (0, 0, 0)$ **represents the baryon** $N\,(939)$ from (41) .

From (42) and (43), the 6 fold degenerate energy bands will be divided into two energy bands with 3 fold degeneracy. For the 3 fold degenerate energy bands, using (2) and (5), we have $I_m = 1$ and $Q = 1, 0, -1$. Comparing the intrinsic numbers S, I, Q

of the energy bands with those of the experimental baryon families $\Sigma(\Sigma^+, \Sigma^0, \Sigma^-)$, we know that each 3 fold degenerate energy band represents a baryon family $\Sigma(\Sigma^+, \Sigma^0, \Sigma^-)$. Furthermore, from (3), we get another possible value of the isospin $I = I_m - 1 = 0$, and $Q = 0$ from (5). Consequently, there is also a baryon Λ with $S = -1$, $I = 0$ and $Q = 0$, corresponding to each Σ family. Using Fig. 2(b), we get

$$
\begin{array}{llllll}
E_P = 3/4 & \vec{n} = (101,011,110) & \varepsilon^{(0)} = 1209 & \Sigma(1209); & \Lambda(1209) \\
E_\Gamma = 2 & \vec{n} = (1\text{-}10,\text{-}110,01\text{-}1, & \varepsilon^{(0)} = 1659 & \Sigma(1659); & \Lambda(1659) \\
 & \quad 0\text{-}11,10\text{-}1,\text{-}101) & \varepsilon^{(0)} = 1659 & \Sigma(1659); & \Lambda(1659) \\
E_\Gamma = 2 & \vec{n} = (\text{-}10\text{-}1,0\text{-}1\text{-}1,\text{-}1\text{-}10) & \varepsilon^{(0)} = 1659 & \Sigma(1659); & \Lambda(1659) \\
E_P = 11/4 & \vec{n} = (020,002,200) & \varepsilon^{(0)} = 1929 & \Sigma(1929); & \Lambda(1929) \\
E_P = 11/4 & \vec{n} = (121,211,112) & \varepsilon^{(0)} = 1929 & \Sigma(1929); & \Lambda(1929) \\
E_\Gamma = 4 & \vec{n} = (0\text{-}20,\text{-}200,00\text{-}2) & \varepsilon^{(0)} = 2379 & \Sigma(2379); & \Lambda(2379) \\
E_P = 19/4 & \vec{n} = (1\text{-}12,\text{-}112,21\text{-}1, & \varepsilon^{(0)} = 2649 & \Sigma(2649); & \Lambda(2649) \\
 & \quad 2\text{-}11,12\text{-}1,\text{-}121) & \varepsilon^{(0)} = 2649 & \Sigma(2649); & \Lambda(2649) \\
E_P = 19/4 & \vec{n} = (202,022,220) & \varepsilon^{(0)} = 2649 & \Sigma(2649); & \Lambda(2649) \\
E_\Gamma = 6 & \vec{n} = (\text{-}211,2\text{-}1\text{-}1,2\text{-}1\text{-}1, & \varepsilon^{(0)} = 3099 & \Sigma(3099); & \Lambda(3099) \\
 & \quad 11\text{-}2,\text{-}12\text{-}11\text{-}21) & \varepsilon^{(0)} = 3099 & \Sigma(3099); & \Lambda(3099) \\
 & \vec{n}=(\text{-}1\text{-}21,1\text{-}2\text{-}1,\text{-}11\text{-}2, & \varepsilon^{(0)} = 3099 & \Sigma(3099); & \Lambda(3099) \\
 & \quad 1\text{-}1\text{-}2,\text{-}21\text{-}1,\text{-}2\text{-}11) & \varepsilon^{(0)} = 3099 & \Sigma(3099); & \Lambda(3099) \\
 & \vec{n}=(\text{-}1\text{-}2\text{-}1,\text{-}1\text{-}1\text{-}2,\text{-}2\text{-}1\text{-}1) & \varepsilon^{(0)} = 3099 & \Sigma(3099); & \Lambda(3099)
\end{array}
\qquad (61)
$$

...

C The Axis $\Sigma(\Gamma - N)$

The axis $\Sigma(\Gamma - N)$ is a 2 fold symmetry axis, $R = 2$ and $S = -2$ from (47). For low energy levels, there are 4 fold degenerate energy bands, 2 fold degenerate energy bands, and single energy bands on the axis (see Fig. 3(a)). According to (42) and (43), each 4 fold energy band will be divided into two 2 fold degenerate energy bands.

C- 1 The two fold degenerate energy bands on the axis $\Sigma(\Gamma - N)$

For the two fold degenerate energy bands (see Fig. 3(a)), $I = 1/2$ from (2), and $Q = 0, -1$ from (5). Comparing the intrinsic numbers S, I, Q of the 2 fold energy band with those of the experimental baryon families $\Xi(\Xi^0,\ \Xi^-)$, we know that each 2 fold degenerate energy band represents a baryon family $\Xi(\Xi^0,\ \Xi^-)$ because they have the same quantum numbers ($I = 1/2$, $S = -2$ and $Q = 0, -1$):

$$
\begin{array}{llll}
E_\Gamma = 2 & \vec{n} = (1\text{-}10,\text{-}110) & \varepsilon^{(0)} = 1659 & \Xi(1659) \\
E_N = 5/2 & \vec{n} = (200,020) & \varepsilon^{(0)} = 1839 & \Xi(1839) \\
E_\Gamma = 4 & \vec{n} = (002,00\text{-}2) & \varepsilon^{(0)} = 2379 & \Xi(2379) \\
 & \vec{n} = (\text{-}200,0\text{-}20) & \varepsilon^{(0)} = 2379 & \Xi(2379) \\
E_N = 9/2 & \vec{n} = (112,11\text{-}2) & \varepsilon^{(0)} = 2559 & \Xi(2559) \\
E_\Gamma = 6 & \vec{n} = (\text{-}1\text{-}12,\text{-}1\text{-}1\text{-}2) & \varepsilon^{(0)} = 3099 & \Xi(3099) \\
\cdots & & &
\end{array}
\tag{62}
$$

C- 2 The four fold degenerate energy bands on the axis $\Sigma(\Gamma - N)$

According to (43), each 4 degenerate energy band (see Fig. 3(a)) on the symmetry axis Σ will be divided into two 2 fold degenerate bands, which represent 2 baryon families $\Xi(\Xi^0,\ \Xi^-)$. Considering that the symmetry axis is a 2 fold rotary symmetric axis, we know that the division is reasonable:

$$
\begin{array}{llll}
E_N = 3/2 & \vec{n} = (101,10\text{-}1,011,01\text{-}1) & \varepsilon^{(0)} = 1479 & 2\ \Xi(1479) \\
E_\Gamma = 2 & \vec{n} = (\text{-}101,\text{-}10\text{-}1,0\text{-}11,0\text{-}1\text{-}1) & \varepsilon^{(0)} = 1659 & 2\ \Xi(1659) \\
E_N = 7/2 & \vec{n} = (121,12\text{-}1,211,21\text{-}1) & \varepsilon^{(0)} = 2199 & 2\ \Xi(2199) \\
E_N = 11/2 & \vec{n} = (\text{-}121,\text{-}12\text{-}1,2\text{-}11,2\text{-}1\text{-}1) & \varepsilon^{(0)} = 2919 & 2\ \Xi(2919) \\
E_\Gamma = 6 & \vec{n} = (1\text{-}12,1\text{-}1\text{-}2,\text{-}112,\text{-}11\text{-}2) & \varepsilon^{(0)} = 3099 & 2\ \Xi(3099) \\
E_\Gamma = 6 & \vec{n} = (1\text{-}21,1\text{-}2\text{-}1,\text{-}211,\text{-}21\text{-}1) & \varepsilon^{(0)} = 3099 & 2\ \Xi(3099) \\
E_\Gamma = 6 & \vec{n} = (\text{-}1\text{-}21,\text{-}1\text{-}2\text{-}1,\text{-}2\text{-}11,\text{-}2\text{-}1\text{-}1) & \varepsilon^{(0)} = 3099 & 2\ \Xi(3099) \\
\cdots & & &
\end{array}
\tag{63}
$$

C- 3 The single energy bands on the axis $\Sigma(\Gamma - N)$

From Fig. 3(a) and Fig. 5(c), we can see that single bands exist on the axis Σ. For the single energy bands, we have $S = -2$, $I = 0$, and $Q = -1/2$ from (5). According to **Hypothesis V**. 6, we have to use (7) instead of (4):

$$S_{\text{Single}} = \bar{S}_{\Sigma} \pm \Delta S = -2 \pm 1. \tag{64}$$

Using (54-B), we can find the ΔS for the single bands. The strange number will take -1 and -3 alternately from the lower to the higher energy bands.

From (58), we can find the energy fluctuations. Since the end points Γ and N of the axis Σ have different symmetries, J will take 0, 1, 2, ... from the lowest energy band to higher ones for each of the two end points respectively. Particularly, at $E_\Gamma = 0$, $J_\Gamma = 0$, $\Delta\varepsilon = 0$, at $E_\Gamma = 2$, $J_\Gamma = 1$, $\Delta\varepsilon = 0$, at $E_\Gamma = 8$, $J_\Gamma = 2$, $\Delta\varepsilon = -200$... Similarly, at $E_N = 1/2$, $J_N = 0$, $\Delta\varepsilon = 0$; at $E_N = 9/2$, $J_N = 1$, $\Delta\varepsilon = 0$; at $E_N = 25/2$, $J_N = 2$, $\Delta\varepsilon = 200$...

At $E_\Gamma = 0$, $J_\Gamma = 0$, $\Delta\varepsilon = 0$ from (58), **the energy band with** $\vec{n} = (0, 0, 0)$ **represents the baryon** $N\,(939)$ from (41) .

At $E_N = 1/2$, $J_N = 0$, $\Delta\varepsilon = 0$ from (58), the second lowest energy band with $\vec{n} = (1, 1, 0)$, $\Delta S = +1$ from (54-B) $\rightarrow S = \overline{S} + \Delta S = -1$. Using (59), the energy of the energy band is $\varepsilon = 1119$ Mev. Therefore, the energy band represents the baryon $\Lambda(1119)$.

At $E_\Gamma = 2$, $J_\Gamma = 1$, $\Delta\varepsilon = 0$ from (58), the third lowest band with $\vec{n}$ = (-1, -1, 0) should have $\Delta S = -1$ from from (54-B). So that $S = -3$, $I = 0$, and $Q = -1$. From the experimental results that the baryon Ω^- [31] has $S = -3$, $I = 0$, and $Q = -1$, we obtain that the energy band represents a baryon $\Omega^-(1659)$.

At $E_N = 9/2$, $J_N = 1 \rightarrow \Delta\varepsilon = 0$ from (58), the fourth band ($\vec{n}$ = (2, 2, 0)) has $\Delta S = +1$ from (54-B), $S = -2 + 1 = -1$,and $J_N = 1$, $\varepsilon = 2559$ Mev. Since $\Delta\varepsilon = 0$, from (9), we infer that this energy band represents a baryon $\Lambda(2559)$.

At $E_\Gamma = 8$, $J_\Gamma = 2$, the fifth one ($\vec{n}$=(-2, -2, 0)$\rightarrow$ ΔS=-1 from (54-B)) has $S = -3$, $I = 0$ and $Q = -1$, so it represents a baryon $\Omega^-(3619)$.

At $E_N = 25/2$, $J_N = 2$, the sixth one ($\vec{n} = (3, 3, 0)$) has $\Delta S = +1$ from (54-B)$\rightarrow$ $S = -2 + 1 = -1$ from (7), and $\varepsilon = 5439 + 200 = 5639$ from (59). According to **Hypothesis V**. 6 (9), we know that the energy band has a bottomed number $b = -1$. It represents a baryon with $I = 0$, $b = -1$, $Q = 0$, and $\varepsilon = 5639$. Since it has a bottomed number $b = -1$, we call this baryon as the **Bottom baryon Λ_b(5639)** [32]. It is very important to pay attention to the **experimentally confirmed bottom baryon Λ_b(5639) born here, on the single energy band, and from the fluctuation** $\Delta S = +1$ and $\Delta\varepsilon = 200$ Mev. Using Fig. 5(c), we find the baryons:

$$
\begin{array}{llllll}
E_N = 1/2 & \vec{n} = (110) & \Delta S = +1 & J_N = 0 & \Delta\varepsilon = 0 & \Lambda(1119) \\
E_\Gamma = 2 & \vec{n} = (\text{-}1\text{-}10) & \Delta S = -1 & J_\Gamma = 1 & \Delta\varepsilon = 0 & \Omega^-(1659) \\
E_N = 9/2 & \vec{n} = (220) & \Delta S = +1 & J_N = 1 & \Delta\varepsilon = 0 & \Lambda(2559) \\
E_\Gamma = 8 & \vec{n} = (\text{-}2\text{-}20) & \Delta S = -1 & J_\Gamma = 2 & \Delta\varepsilon = -200 & \Omega^-(3619) \\
E_N = 25/2 & \vec{n} = (330) & \Delta S = +1 & J_N = 2 & \Delta\varepsilon = 200 & \Lambda_b(5639) \\
E_\Gamma = 18 & \vec{n} = (\text{-}3\text{-}30) & \Delta S = -1 & J_\Gamma = 3 & \Delta\varepsilon = -400 & \Omega^-(7019) \\
E_N = 49/2 & \vec{n} = (440) & \Delta S = +1 & J_N = 3 & \Delta\varepsilon = 400 & \Lambda_b(10159) \\
\ldots & & & & &
\end{array}
\tag{65}
$$

D The Axis $D(P - N)$

The axis $D(P-N)$ is a 2 fold rotary symmetry axis, $R = 2$. It is parallel to the axis Δ (see Fig. 1), thus $S = 0$ from (48). For low energy levels, there are 4 fold degenerate energy bands and 2 fold degenerate energy bands on the axis (see Fig. 3(b)).

D- 1 The four fold energy bands on the axis $D(P - N)$

From Fig. 3(b), we can see that there are 4 fold degenerate energy bands on the axis. Using (2), we get $I = 3/2$, and from (5), we get $Q = 2, 1, 0, -1$. From the fact [10] that the baryon families $\Delta(\Delta^{++}, \Delta^+, \Delta^0, \Delta^-)$ have $S = 0$, $I = 3/2$, and $Q = 2, 1,$

0,-1 we know that each 4 fold degeneracy energy band represents a baryon family Δ. However, each 4 fold degenerate energy band has 4 asymmetric $\vec{n}$ values. They can be divided into two groups at the point N (with 50% possibility at the point P). Each of them has 2 symmetric $\vec{n}$ values. Using (2), we get $I = 1/2$, and from (5), we get $Q = 1$, 0. From the fact [10] that the baryon families $N(N^+, N^0)$ have $S = 0$, $I = 1/2$, and $Q = 1$, 0, we know that each 2 fold sub-degeneracy energy band represents a baryon family N. Hence, for the 4 fold energy bands we have

$$
\begin{array}{llll}
E_N = 5/2 & \vec{n} = \text{(1-10,-110,020,200)} & \varepsilon^{(0)} = 1839 & \\
\Delta S = 0 & \vec{n} = \text{(1-10,-110)} & S = 0 & N(1839) \\
\Delta S = 0 & \vec{n} = \text{(020,200)} & S = 0 & N(1839) \\
E_P = 11/4 & \vec{n} = \text{(-101,0-11,211,121)} & \varepsilon^{(0)} = 1929 & \Delta(1929) \\
\Delta S = 0 & \vec{n} = \text{(-101,0-11)} & S = 0 & N(1929) \\
\Delta S = 0 & \vec{n} = \text{(211,121)} & S = 0 & N(1929) \\
E_N = 7/2 & \vec{n} = \text{(12-1,21-1,-10-1,0-1-1)} & \varepsilon^{(0)} = 2199 & \\
\Delta S = 0 & \vec{n} = \text{(12-1,21-1)} & S = 0 & N(2199) \\
\Delta S = 0 & \vec{n} = \text{(-10-1,0-1-1)} & S = 0 & N(2199) \\
E_P = 19/4 & \vec{n} = \text{(-112,1-12,202,022)} & \varepsilon^{(0)} = 2649 & \Delta(2649) \\
\Delta S = 0 & \vec{n} = \text{(-112,1-12)} & S = 0 & N(2649) \\
\Delta S = 0 & \vec{n} = \text{(202,022)} & S = 0 & N(2649) \\
\ldots &&&
\end{array}
\tag{66}
$$

D- 2 The two fold energy bands on the axis $D(P - N)$

There are symmetric and asymmetric $\vec{n}$ values in the 2 fold energy bands (see Fig. 3(b)). The 2 fold energy bands with symmetric $\vec{n}$ values will not be divided because the degeneracy is not greater than the rotary number ($d = R = 2$). The bands have $S = 0$, $I = 1/2$, and $Q = +1$, 0. Since the experimental baryon family $N(N^+,N^0)$ has the same S, I and Q, we know that the two energy bands represent a baryon family N. However, the case for 2 fold energy bands with asymmetric $\vec{n}$ values is not so simple.

At $E_N = 1/2$, $J_N = 0 \rightarrow \Delta\varepsilon = 0$ from (58), there are two energy bands with asymmetric $\vec{n} = (000, 110)$. Since the two energy bands are in different Brillouin zones,

they will be divided into 2 single bands. The energy band with $\vec{n} = (110)$ belongs to the second Brillouin zone, and it represents the baryon $\Lambda(1119)$ with S = -1 from the first row of (65). For another band with $\vec{n} = (000)$, it represents the baryon $N(939)$ from (41).

At $E_P = 11/4$, $J_P = 1 (J_P = 0$ at $E_P = 3/4) \rightarrow \Delta\varepsilon = 0$ from (58), $\vec{n} = (002, 112) -$ asymmetric $\vec{n}$ values. Using (44), the two energy bands may be divided with a possibility of 50%. However, the fluctuation of energy $\Delta\varepsilon = 0$, hence there is not enough energy fluctuation for the two bands to be divided. Thus, the two energy bands may not be divided. They represent a baryon family $N(1929)$.

There are two asymmetric 2 fold energy bands at $E_N = 9/2$ ($\vec{n} = (220, -1 - 10)$ and $\vec{n} = (11 - 2, 00 - 2)$). Using (58), the energy fluctuation for the first 2 energy bands ($\vec{n} = (220, -1 - 10)$, $J_N = 1$) is $\Delta\varepsilon = 0$. Hence, they can not be divided. They represent a baryon family $N(2559)$. However, the energy fluctuation for the second 2 energy bands ($\vec{n} = (11 - 2, 00 - 2)$, $J_N = 2$) is $\Delta\varepsilon = 200(2 - 1)\Delta S = 200\Delta S$. Using (44), the 2 fold bands should be divided into 2 single energy bands. Thus, from (7), $S = 0 + \Delta S = \pm 1$. According to (8), one of the 2 single energy bands ($\vec{n} = (00 - 2)$ from (60)) has a charmed number $C = S = +1$ (with $I = 0$ and $Q = +1$), and it represents a Charmed baryon $\Lambda_C^+(2759)$; the other has a strange number $S = -1$ (with $I = 0$ and $Q = 0$), and it represents a baryon $\Lambda(2359)$.

Therefore, we have

$$
\begin{array}{llll}
E_N = 1/2 & \vec{n} = (000,110) & \varepsilon^{(0)} = 1119 & \\
J_N = 0 & \vec{n} = (000) & \text{S=C=b=0} & N(939) \\
\Delta\varepsilon = 0 & \vec{n} = (110) & S = -1 & \Lambda(1119) \\
E_P = 3/4 & \vec{n} = (101,011) & \varepsilon^{(0)} = 1209 & N(1209) \\
E_N = 3/2 & \vec{n} = (10\text{-}1,01\text{-}1) & \varepsilon^{(0)} = 1479 & N(1479) \\
E_P = 11/4 & \vec{n} = (002,112) & \varepsilon^{(0)} = 1929 & \\
J_P = 1 & \Delta S = 0 & \Delta\varepsilon = 0 & N(1929) \\
E_N = 9/2 & & \varepsilon^{(0)} = 2559 & \\
J_N = 1 & \vec{n} = (220,\text{-}1\text{-}10) & \Delta\varepsilon = 0 & N(2559) \\
J_N = 2 & \vec{n} = (11\text{-}2,00\text{-}2) & & \\
\vec{n}\text{=}00\text{-}2 & \Delta S = +1 & \Delta\varepsilon = +200 & \Lambda_C^+(2759) \\
\vec{n}\text{=}11\text{-}2 & \Delta S = -1 & \Delta\varepsilon = -200 & \Lambda(2359) \\
E_P = 19/4 & \vec{n} = (\text{-}121,2\text{-}11) & \varepsilon^{(0)} = 2649 & N(2649) \\
E_N = 11/2 & \vec{n} = (2\text{-}1\text{-}1,\text{-}12\text{-}1) & \varepsilon^{(0)} = 2919 & N(2919) \\
\cdots & & &
\end{array} \tag{67}
$$

E The Axis $F(P-H)$

The axis $F(P-H)$ is a 3 fold symmetry axis, from (49), $S=-1$. For low energy levels, there are 6 fold energy bands, 3 fold energy bands, and single energy bands on the axis (see Fig. 4(a)).

E- 1 The single energy bands on the axis $F(P-H)$

For the single energy band, the strange number $S=-1$, and $I=Q=0$ from (2) and (5). Each single energy band represents a baryon Λ. From Fig. 4(a) we have

$$
\begin{array}{lllllll}
E_P = 3/4 & \vec{n} = (110) & \varepsilon^{(0)} = 1209 & S = -1 & I = Q = 0 & \Lambda(1209) \\
E_H = 3 & \vec{n} = (\text{-}1\text{-}12) & \varepsilon^{(0)} = 2019 & S = -1 & I = Q = 0 & \Lambda(2019) \\
\cdots & & & & &
\end{array} \tag{68}
$$

E- 2 The three fold energy bands on the axis $F(P-H)$

For the 3 fold energy band (see Fig. 4(a)), $S=-1$, $I=1$ from (2), and $Q=1,0,-1$ from (5). Comparing them with the experimental result that the families $\Sigma(\Sigma^+,\ \Sigma^0,\ \Sigma^-)$ have the same intrinsic quantum numbers, we find that the 3 fold degenerate energy bands represent the baryon families $\Sigma(\Sigma^+,\ \Sigma^0,\ \Sigma^-)$. For another possible isospin, we have $I=0$ from (3), and $Q=0$ from (5). This suggests the existence of another baryon Λ. Using (44), we know that the 3 fold degenerate energy bands (all have asymmetric $\vec{n}$ values) will not be divided at the point H, but may be divided at the point P with a possibility of 50%. The division at point P will result in a single band representing a baryon Λ, and a 2 fold baryon (with symmetric $\vec{n}$ values) representing a baryon family N ($\Delta S=+1$) or $\Xi(\Delta S=-1)$.

At $E_P=3/4$, $J_P=0$, the 3 energy bands with asymmetric $\vec{n}=(000,101,011)$ are in different Brillouin zones. They will be divided into a single band with $\vec{n}=(000)$ (in the first Brillouin zone) and a two fold energy band with $\vec{n}=(101,011)$ (in the second Brillouin zone). **The single energy band with $\vec{n}=(\mathbf{0},\mathbf{0},\mathbf{0})$ represents $N(939)$ from (41).** The two fold energy band with $\vec{n}=(101,011)$ represents $N(1209)$ from the fourth line of (67).

At $E_P=11/4$, $\vec{n}=(112,1-10,-110)$, $J_P=1\rightarrow\Delta\varepsilon=0$ from (57). Since $\Delta\varepsilon=0$, the three energy bands will not be divided (see (44)). Thus, the energy bands represent $\Sigma(1929)$ and $\Lambda(1929)$.

At $E_P=19/4$, $J_P=2\rightarrow\Delta\varepsilon=-100\Delta S$ from (57), the three energy bands with $\vec{n}=$ (220,21-1,12-1) may be divided with a possibility of 50% (see (44)). Hence the energy bands may represent $\Sigma(2649)$ and $\Lambda(2649)$ (if not divided), or $2\Lambda(2649)$ and $N(2549)$ or $\Xi(2749)$ (if divided).

We have

$E_P = 3/4$	$\vec{n} = (000,011,101)$	$\varepsilon^{(0)} = 1209$	
$J_P = 0$	$\vec{n} = (000)$	S=C=b=0	$N(939)$
$\Delta\varepsilon = 0$	$\vec{n} = (011,101)$	$\Delta S = +1$	$N(1209)$
$E_H = 1$	$\vec{n} = (002,\text{-}101,0\text{-}11)$	$\Sigma(1299)$	$\Lambda(1299)$
$E_P = 11/4$	$\vec{n} = (112,1\text{-}10,\text{-}110)$	$\Sigma(1929)$	$\Lambda(1929)$
$J_P = 1$	$\Delta\varepsilon = 0$		
$E_H = 3$	$\vec{n} = (\text{-}1\text{-}10,112,1\text{-}12)$	$\Sigma(2019)$	$\Lambda(2019)$
$E_P = 19/4$	$\vec{n} = (220,21\text{-}1,12\text{-}1)$	$\Sigma(2649)$	$\Lambda(2649)$
$J_P = 2$	$\vec{n} = (220)$	$\Delta S = 0$	$\Lambda(2649)$
$\Delta\varepsilon = -100$	$\vec{n} = (21\text{-}1,12\text{-}1)$	$\Delta S = +1$	$N(2549)$
		$\Delta S = -1$	$\Xi(2749)$

(69)

...

E- 3 The six fold energy bands ($d = 6$) on the axis $F(P - H)$

The 6 fold energy bands on the axis F are a special case. The 6 asymmetric $\vec{n}$ values consist of three groups, each of them has 2 symmetric $\vec{n}$ values. However, since the symmetry axis F has a rotary $R = 3$, there are two ways to divide the energy bands: A) dividing the energy bands according to (42) and (43); B) dividing the energy bands according to the symmetry of $\vec{n}$ values.

(A). From (42) and (43), each 6 fold energy band will be divided into two 3 fold energy bands first. Since each 3 fold sub-degeneracy band has asymmetric $\vec{n}$ values, according to (44), the 3 energy bands may be divided (second division) further at point P with a possibility of 50%, but not be at the point H. If the two 3 fold sub-degeneracy bands are not divided further, they will represent two baryon families $\Sigma(\Sigma^+, \Sigma^0, \Sigma^-)$ ($S = -1$, $I = 1$, $Q = 1, 0, -1$). However, if the second division occurs at the point P, in order to keep (6), both of the two 3 fold sub-degeneracy bands will be divided, resulting in two 2 fold bands (one with $\Delta S = +1$, the other with $\Delta S = -1$) and two single bands. According to (12), the 2 fold energy band with $\Delta S = +1$ will keep S unchanged while

increasing the Charmed number C by 1. Thus, the two 2 fold energy bands represent a baryon family $\Xi_C(\Xi_C^+,\ \Xi_C^0)$ ($C=+1,\ S=-1,\ I=1/2,\ Q=1,\ 0$) and a baryon family $\Xi(\Xi^0,\ \Xi^-)$ ($S=-2,\ I=1/2,\ Q=0,-1$), while the two single bands represent two Λ baryons ($S=-1,\ I=0,\ Q=0$).

At $E_P=11/4$, $\vec{n}=$ (01-1,10-1,121,211,020,200), $J_P=1$ ($J_P=0$ at $E_P=3/4$), $\Delta\varepsilon=0$ from (57). Since there is not enough fluctuation energy to divide the two 3 fold sub-degeneracies (44), they are not divided. Thus, the 6 fold band represents

$$\Sigma(1929)_{(01\text{-}1,10\text{-}1,121)}+\Sigma(1929)_{(211,020,200)}\ \text{and}\ \Lambda(1929)_{121}+\Lambda(1929)_{211} \tag{70}$$

At $E_P=19/4$, $\vec{n}=$ (202,022,-121,2-11,0-1-1,-10-1), $J_P=2$. According to (57), the energy fluctuation $\Delta\varepsilon=-100\times\Delta S$. Thus, the two 3 fold bands represent (with a possibility of 50% to be divided at the point P)

$$\Sigma(2649)+\Sigma(2649)\rightarrow[\Xi_C(2549)+\Lambda(2649)]+[\Xi(2749)+\Lambda(2649)] \tag{71}$$

It is very important to pay attention to the **baryon** $\Xi_C(2549)_{(202,\ 022)}$[33] **born here, on the 6 fold energy band, after the second division from the fluctuation** $\Delta S=+1$ and $\Delta\varepsilon=-100$ Mev.

At $E_H=5$, $\vec{n}=$ (0-20,-200,-211,1-21,013,103). According to (44), the two 3 fold sub-degeneracies are not divided. Thus, the 6 fold band represents

$$\Sigma(2739)+\Sigma(2739)\ \text{and}\ \Lambda(2739)+\Lambda(2739) \tag{72}$$

At $E_H=5$, $\vec{n}=$ (0-22,-202,-2-11,-1-21,0-13,-103). Similarly, we have

$$\Sigma(2739)+\Sigma(2739)\ \text{and}\ \Lambda(2739)+\Lambda(2739) \tag{73}$$

At $E_P=27/4, \vec{n}=$ (-12-1,2-1-1,301,031,222,00-2), $J_P=3$. Similar to the case of $E_P=19/4$, $\Delta\varepsilon=-200\times\Delta S$ and the 6 fold band represents (with *a* possibility of 50% to be divided at the point P)

$$2\ \Sigma(3369)\rightarrow[\Xi_C(3169)+\Lambda(3369)]+[\Xi(3569)+\Lambda(3369)]\ ... \tag{74}$$

(B). According to the symmetry values of $\vec{n}$, each 6 fold degeneracy can be divided into a 2 fold sub-degeneracy and a 4 fold sub-degeneracy. Since this kind of division will result in partial charges from (4) and (5), we get $S = \bar{S} + \Delta S = -1 \pm 1$ from (7). To keep (6), the 2 fold energy band will have $\Delta S = -1$, while the 4 fold band will have $\Delta S = +1$. (Another possibility is that the 2 fold energy band has $\Delta S = +1$, while the 4 fold band has $\Delta S = -1$ ($S = -2$). However, the possibility of obtaining a 4 fold band with strange number $S = -2$ is very small. Hence, it will be ignored here).

Since the symmetric axis is a 3 rotary one, the 4 fold energy band will be divided further. In order to balance the 3 rotary symmetry of the axis and the 2 fold symmetry of the $\vec{n}$ values, the second division should **keep the 3 rotary symmetry** (**may break the 2 fold symmetry of** $\vec{n}$) because the first division has kept the 2 fold symmetry of the $\vec{n}$ values. Thus, the 4 fold energy band ($S = -1 + 1 = 0$, Δ family) may be divided into $(\Lambda_C^+ + \Sigma)$ or $(\Lambda + \Sigma_C)$ (if $\Delta\varepsilon \neq 0$). But if $\Delta\varepsilon = 0$, the Δ family may not be divided because the above division requires the fluctuation of energy. When the energy increases, the fluctuation of energy ($\Delta\varepsilon$) also increases, so the probability of further division increases as well.

At $E_P = 11/4$, $\vec{n}$ = (01-1,10-1,121,211,020,200), $J_P = 1$, $\Delta\varepsilon = 0$ from (57). Since $\Delta\varepsilon = 0$, the 4 fold energy band $\Delta(1929)$ may not be divided. From Fig. 2(b),we can see that there are 3 energy bands at the point P: (1) $E_\Gamma = 2 \rightarrow E_P = 11/4$, $\vec{n}$ = (1-10, -110, 01-1, 0-11, 10-1, -101); (2) $\mathrm{E}_P = 11/4 \rightarrow E_\Gamma = 4$, $\vec{n}$ = (200, 020, 200); (3) $\mathrm{E}_P = 11/4 \rightarrow E_\Gamma = 6$, $\vec{n} = (121, 211, 112)$. Two near bands may partly degenerate a 4 fold band ($\Delta(1929)$):

$$\vec{n} = (121, 211), \Xi(1929); \vec{n} = (01\text{-}1, 10\text{-}1, 020, 200), \Delta(1929). \tag{75}$$

or

$$\vec{n} = (01\text{-}1,10\text{-}1), \Xi(1929);\ \vec{n} = (020, 200, 121, 211), \Delta(1929).$$

At $E_P = \frac{19}{4}$, $\vec{n}$ = (0-1-1,-10-1,-121,2-11,202,022), $J_P = 2$, the energy fluctuation $\Delta\varepsilon = -100(2-1)\Delta S = -100 \times \Delta S$ from (57). After the first division, we have a baryon $\Xi(2749)$ and a baryon $\Delta(2549)$. For $\Delta(2549)$, using (7), we get $S = 0 + \Delta S == \pm 1$. From $\Delta S = \pm 1$, we have $\Delta(2549) \rightarrow \{[\Lambda_C^+(2449)\ (\ \Delta S = +1\ ) + \Sigma(2649)\ (\Delta S = -1\ )]$ or $[\Sigma_C(2449)\ (\ \Delta C = \Delta S = +1\ )$(see (12)) $+\Lambda(2649)\ (S = -1)]\}$ to keep the 3 rotary symmetry. It is very important to pay attention to the **baryon $\Sigma_C(2449)$ born here, on the 6 fold energy band of the axis F, after the second division from the fluctuation** $\Delta S = +1$ and $\Delta\varepsilon = -100$ Mev. To sum up, the 6 fold energy band has the possibility to represent baryon families:

$$\Xi(2749),\ \Sigma(2649),\ \Lambda_C^+(2449),\ \Sigma_C(2449),\ \Lambda(2649). \tag{76}$$

At $E_H = 5$, $\vec{n}$ = (0-20,-200,-211,1-21,013,103), $J_H = 1$ the energy fluctuation $\Delta\varepsilon = 0$ from (57). We have:

$$\Xi(2739),\ \Delta(2739). \tag{77}$$

Also at $E_H = 5$, $\vec{n}$ = (0-22,-202,-2-11,-1-21,0-13,-103), $J_H = 2$, the energy fluctuation $\Delta\varepsilon = -100 \times \Delta S$ from (57). We have:

$$\Xi(2839),\ \Sigma(2739),\ \Lambda_C^+(2539),\ \Sigma_C(2539),\ \Lambda(2739). \tag{78}$$

At $E_P = 27/4$, $\vec{n}$ = (-12-1,2-1-1,301,031,222,00-2), $J_P = 3$. Similar to the case of $E_P = 19/4$, $\Delta\varepsilon = -200 \times \Delta S$ from (57) and we have

$$\Xi(3569),\ \Sigma(3369),\ \Lambda_C^+(2969),\ \Sigma_C(2969),\ \Lambda(3369). \tag{79}$$

F The Axis $G(M-N)$

The axis $G(M-N)$ is a 2 fold symmetry axis. From (50), the strange number $S=-2$. There are 6, 4, and 2 fold energy bands on the axis (see Fig. 4(b)).

F- 1 The two fold energy bands on the axis $G(M-N)$

For the 2 fold energy band (see Fig. 4(b)), $S=-2$, $I=1/2$ from (2), and $Q=0,-1$ from (5). From the experimental results that the family Ξ (Ξ^0,Ξ^-) has the same intrinsic quantum numbers, we find that each 2 fold degenerate energy band with symmetric $\vec{n}$ values represents a baryon family Ξ (Ξ^0,Ξ^-).

At $E_N=1/2$, $J_N=0$, $\Delta\varepsilon=0$ from (58), the two energy bands with asymmetric $\vec{n}=(000,110)$ are in the first and second Brillouin zones, respectively. So they will be divided. The energy band with $\vec{n}=(110)$ (in the second Brillouin zone) represents $\Lambda(1119)$ with S = -1. Another band with $\vec{n}=(000)$ (in first Brillouin zone) **represents** $N(939)$ from (41).

At $E_M=1$, there are two 2 fold energy bands. The 2 fold energy band with symmetric values $\vec{n}=(101,10-1)$ represents the baryon families $\Xi(1299)$. Another 2 fold energy band with asymmetric values $\vec{n}=(200,1-10)$ will not be divided (see (44)), it represents the baryon family $\Xi(1299)$, too.

At $E_N=5/2$, $J_N=1$, $\Delta\varepsilon=0$ from (58). Since $\Delta\varepsilon=0$ the 2 fold energy band with $\vec{n}=(020,110)$ should not be divided (see (44)), it represents the baryon family $\Xi(1839)$.

At $E_M=5$, the 2 fold energy band with asymmetric $\vec{n}=$ (3-10,2-20) will not be divided (see (44)), it represents the baryon family $\Xi(2739)$.

Thus, we have

$$
\begin{array}{lllll}
E_N = 1/2 & \vec{n} = (000,110) & \varepsilon^{(0)} = 1119 & & \\
J_N = 0 & \vec{n} = (000) & \text{S=C=b=0} & N(939) & \\
 & \vec{n} = (110) & S = -1 & \Lambda(1119) & \\
E_M = 1 & \vec{n} = (101,10\text{-}1) & \varepsilon^{(0)} = 1299 & \Xi(1299) & \\
 & \vec{n} = (200,1\text{-}10) & \varepsilon^{(0)} = 1299 & \Xi(1299) & \\
E_N = 3/2 & \vec{n} = (011,01\text{-}1) & \varepsilon^{(0)} = 1479 & \Xi(1479) & \\
E_N = 5/2 & \vec{n} = (020,\text{-}110) & \varepsilon^{(0)} = 1839 & \Xi(1839) & \\
J_N = 1 & & \Delta\varepsilon = 0 & & \\
E_M = 3 & \vec{n} = (2\text{-}11,2\text{-}1\text{-}1) & \varepsilon^{(0)} = 2019 & \Xi(2019) & \\
E_M = 5 & \vec{n} = (3\text{-}10,2\text{-}20) & \varepsilon^{(0)} = 2739 & \Xi(2739) & \\
E_N = 11/2 & \vec{n} = (\text{-}121,\text{-}12\text{-}1) & \varepsilon^{(0)} = 2919 & \Xi(2919) & \\
\cdots & & & &
\end{array}
\tag{80}
$$

F- 2 The four fold energy bands on the axis $G(M-N)$

According to (42) and (43), each 4 fold energy band will be divided into two 2 fold energy bands which represent two baryons Ξ:

$$
\begin{array}{lllll}
E_M = 3 & \vec{n} = (0\text{-}11,0\text{-}1\text{-}1, & 211,21\text{-}1) & \varepsilon^{(0)} = 2019 & \\
\Delta S = 0 & \vec{n} = (0\text{-}11,0\text{-}1\text{-}1) & \Xi(2019) & \vec{n} = (211,21\text{-}1) & \Xi(2019) \\
E_N = 7/2 & \vec{n} = (\text{-}101,\text{-}10\text{-}1, & 121,12\text{-}1) & \varepsilon^{(0)} = 2199 & \\
\Delta S = 0 & \vec{n} = (\text{-}101,\text{-}10\text{-}1) & \Xi(2199) & \vec{n} = (121,12\text{-}1) & \Xi(2199) \\
E_M = 5 & \vec{n} = (301,30\text{-}1, & 1\text{-}21,1\text{-}2\text{-}1) & \varepsilon^{(0)} = 2739 & \\
\Delta S = 0 & \vec{n} = (301,30\text{-}1) & \Xi(2739) & \vec{n} = (1\text{-}21,1\text{-}2\text{-}1) & \Xi(2739) \\
\cdots & & & &
\end{array}
\tag{81}
$$

F- 3 The six fold energy bands on the axis $G(M-N)$

According to (42) and (43), each 6 fold energy band will be divided into three 2 fold energy bands. One of the three 2 fold sub-degeneracy energy bands has asymmetric $\vec{n}$ values. According to (44), the 2 energy bands should be divided further at the point N, but not be at the point M. Thus, at point M the each 6 fold energy band will represent

three baryon families Ξ. At the point N, each 6 fold energy band will represent two Ξ and two single energy bands .

At $E_N = 9/2$, $\vec{n} = (112, 11-2, 002, 00-2, 220, -1-10)$. The 6 fold energy band will be divided into: $\vec{n} = (112, 11-2)$ ($\Xi(2559)$), $\vec{n} = (002, 00-2)$ ($\Xi(2559)$), $\vec{n} = (220, -1-10)$. Then the two energy bands with asymmetric $\vec{n}$ values ($\vec{n} = (220, -1-10)$) will be further divided. The fluctuation of energy associated with this division is $\Delta\varepsilon = 200(2-1)\Delta S = 200\Delta S$ Mev from (58) ($J_N = 2$ at $E_N = 9/2$ for 2-fold asymmetric $\vec{n}$ values, $J_N = 0$ at $E_N = 1/2$ and $J_N = 1$ at $E_N = 5/2$ (see (80)). Since this is the second division of the 6 fold energy band, according to **Hypothesis V. 7, (12),** for $\Delta S = +1$ we can get a Charmed number $C = +1$ while keeping the Strange number $S = -2$ unchanged. Hence the 2 energy bands will be divided into $\vec{n} =$ (-1,-1, 0) $\Delta S = +1$ from (65) and $\vec{n} = (2, 2, 0)$ $\Delta S = -1$

$$\Delta C = \Delta S = +1, \ \Omega_C(2759); \qquad \Delta S = -1, \ \Omega(2359). \tag{82}$$

It is very important to pay attention to **the baryon Ω_C(2759)** [35] **born here**, on the 6 fold energy band of the axis G, after the second division with fluctuations $\Delta S = +1$ and $\Delta\varepsilon = +200$ Mev.

At $E_M = 5$, $\vec{n} = (202, 20-2, 1-12, 1-1-2, 310, 0-20)$ will be divided into three 2 fold energy bands, representing 3 baryon families $\Xi(2739)$. The 2 fold band with asymmetric $\vec{n} = (310, 0-20)$ will not be divided further at the point M from (44).

At $E_N = 13/2$, $\vec{n} = (-112, -11-2, 022, 02-2, 130, -200)$, similar to $E_N = 9/2$, the 6 fold degeneracy will be divided into two 2 fold degeneracies, representing two baryon families $\Xi(3279)$. The second division will result a baryon $\Omega_C(3679)$ and a baryon $\Omega(2879)$ ($J_N = 3$ and $\Delta\varepsilon = 200(3-1)\Delta S = 400\Delta S$ Mev).

We have

$$
\begin{array}{lllll}
E_N = 9/2 & \vec{n} = (112,11\text{-}2,002, & & \varepsilon^{(0)} = 2559 & \\
 & \quad 00\text{-}2,220,\text{-}1\text{-}10) & & & \\
J_N = 2 & \vec{n} = (112,11\text{-}2) & \Xi(2559) & \vec{n} = (002,00\text{-}2) & \Xi(2559) \\
\text{(divided)} & \vec{n} = (220) & \Omega_C(2759) & \vec{n} = (\text{-}1\text{-}10) & \Omega(2359) \\
E_M = 5 & \vec{n} = (202,20\text{-}2,1\text{-}12, & & \varepsilon^{(0)} = 2739 & 3\ \Xi(2739) \\
 & \quad 1\text{–}1\text{-}2,310,0\text{-}20) & & & \\
E_N = 13/2 & \vec{n} = (\text{-}112,\text{-}11\text{-}2,022, & & \varepsilon^{(0)} = 3279 & \\
 & \quad 02\text{-}2,130,\text{-}200) & & & \\
J_N = 3 & \vec{n} = (\text{-}112,\text{-}11\text{-}2) & \Xi(3279) & \vec{n} = (022,02\text{-}2) & \Xi(3279) \\
\text{(divided)} & \text{single band} & \Omega_C(3679) & \text{single band} & \Omega(2879) \\
\ldots & & & &
\end{array}
\tag{83}
$$

Continuing above procedure, we can use Fig. 2-5 to find the whole baryon spectrum. Our results are shown in Tables 1 though 6 of Section V.

V Comparing Results

We compare the theoretical results of the BCC model to the experimental results [10] using Tables 1-6. In the comparison, we will use the following laws:

(1) We do not take into account the angular momenta of the experimental results. We assume that the small differences of the masses in the same group of baryons originate from their different angular momenta. If we ignore this effect, their masses should be essentially the same.

(2) We use the baryon name to represent the intrinsic quantum numbers as shown in the second column of Table 1.

(3) For low energy cases, the baryons from different symmetry axes with the same S, C, b, Q, I, I_Z, and $\overrightarrow{n}$ value, as well as in the same Brillouin zone are regarded as the same baryon. The mass of the baryon is the lowest value of their masses. For example,

$\Lambda(1119)$ with $\overrightarrow{n} = (1, 1, 0)$ on the axis Σ (see (65)), $\Lambda(1119)$ with $\overrightarrow{n} = (1, 1, 0)$ on the axis D (see (67)), $\Lambda(1119)$ with $\overrightarrow{n} = (1, 1, 0)$ on the axis G (see (80)) and $\Lambda(1209)$ with $\overrightarrow{n} = (1, 1, 0)$ (see (61) and (68) are all in the second Brillouin zone (the same energy curved surface in the three dimension phase space), they are the same baryon $\Lambda(1119)$.

(4) If the same kind of baryons with the same mass but different $\overrightarrow{n}$ values, then the possibility of discovery of the baryon with symmetry $\overrightarrow{n}$ values is much larger than the possibility of discovery of the baryon with asymmetry $\overrightarrow{n}$ values. Thus, we can ignore the baryon with asymmetry $\overrightarrow{n}$ values in the comparison. For example, $\Xi(1839)$ has two possibility groups of values: (2, 0, 0; 0, 2, 0) and (0, 2, 0; -1, 1, 0). We can ignore the baryon with the asymmetric $\overrightarrow{n}$ = (0, 2, 0; -1, 1, 0). However, if there is no same kind of baryons with the same mass and symmetric $\overrightarrow{n}$ values, then we can not ignore the baryon with asymmetric $\overrightarrow{n}$ values. For example, $\Delta(1929)$ has two possible groups of $\overrightarrow{n}$ values $\overrightarrow{n}$ = (-101, 0-11, 121,211) and $\overrightarrow{n}$ = (01-1, 10-1, 020, 200), we can not ignore either.

A The Ground States of Various Kinds of Baryons

The ground states of various kinds of baryons are shown in Table 1. These baryons have a relatively long lifetime and are the most important experimental results of the baryons. The theoretical results are listed below. From the list, for the long lifetime baryons, we can see some interesting facts: (1) the unflavored baryon N(939) has $\overrightarrow{n}$ = (0, 0, 0); (2) the strange baryons ($\Lambda(1119)$, $\Sigma(1209)$, $\Xi(1299)$, and $\Omega(1659)$) have $\overrightarrow{n}$ values with two components ±1 and one component 0; (3) the charmed baryons ($\Lambda_c^+(2279)$, $\Sigma_c(2449)$, $\Xi_c(2549)$, and $\Omega_c(2759)$) have $\overrightarrow{n}$ values with at least one component ±2; (4) the bottom baryon $\Lambda_b(5639)$ has a $\overrightarrow{n}$ value with 2 components 3; (5) the family $\Delta(1299)$ is a special case, they are not long lifetime particles.

Baryon	N(939)	$\Lambda(1119)$	$\Sigma(1209)$	$\Xi(1299)$	$\Omega(1659)$	$\Lambda_c^+(2279)$
$n_1n_2n_3$	0, 0, 0	1, 1, 0	110,101,011	101,10-1	-1, -1, 0	0, 0, -2
(Eq. No)	(41)	(65)	(61)	(80)	(65)	(60)

Baryon	$\Sigma_c(2449)$	$\Xi_c(2549)$	$\Omega_c(2759)$	$\Lambda_b(5639)$	$\Delta(1299)$
$n_1n_2n_3$	202,022,2-11.	202,022.	2, 2, 0.	3, 3, 0.	101,-101,011,0-11
(Eq. No)	(76)	(71)	(82)	(65)	(51)

From Table 1, we can see that all theoretical intrinsic quantum numbers (isospin I, strange number S, charmed number C, bottom number b, and electric charge Q) are the same as experimental results. Also the theoretical mass values are in very good agreement with the experimental values.

B The Unflavored Baryons N and Δ

A comparison of the theoretical results with the experimental results of the unflavored baryons N and Δ is made in Table 2.

The theoretical results of the low energy baryons Δ are given by the following list. In the list, we give all possible $\overrightarrow{n}$ values and the equation numbers inside the"( )" in whith the baryons Δ are deduced. The $\overrightarrow{n}$ values $1, \pm 1, 0$ represent two $\overrightarrow{n}$ values (1,+1, 0) and (1, -1, 0)... .

Baryon	$\Delta(1299)$	$\Delta(1659)$	$\Delta(1929)$	$\Delta(2019)$	$\Delta(2379)$	$\Delta(2649)$*
$n_1n_2n_3$ (Eq. No)	1,0,1 -1,0,1 0,1,1 0,-1,1 (51)	1,±1,0 -1,±1,0 (51) ±1,0,-1 0,±1,-1 (51)	-101,0-11 211,121 (66) 01-1,10-1 020,200 (75)	1,1,2 1,-1,2 -1,1,2 -1,-1,2 (51)	2,0,0 -2,0,0 0,2,0 0,-2,0 (51)	-1,1,2 1-12 2, 0, 2 0,2,2 (66)
Theory	$\Delta(1299)$	$2\Delta(1659)$	$2\Delta(1929)$	$\Delta(2019)$	$\Delta(2379)$	$\Delta(2649)$

$*$next $\Delta(2739)\overrightarrow{n}=$ ±1±21,±2±11;±1±21,±2±11; ±202,0±22;0±13,±103 $5\Delta(2739)$

The theoretical results of the low energy baryons N are given by the following list. In the list, we give all possible $\overrightarrow{n}$ values and the equation numbers inside the"( )" in whith the baryons N are deduced. We also show how to get the final theoretical results of the baryon N. For example, the baryon N(1209) with $\overrightarrow{n}$ = (0,1,1; 1,0,1) (see Eq. (67)), the baryon N(1209) with $\overrightarrow{n}$ = (0,1,1; 1,0,1) (see Eq. (69)), and the baryon N(1299) with $\overrightarrow{n}$ = (0,1,1; 1,0,1) (see Eq. (51)) are the same baryon N(1209); the baryon N(1929) with $\overrightarrow{n}$ = (0, 0, 2; 1, 1, 2) (67) is ignored since the $\overrightarrow{n}$ values are asymmetry valuers.

Baryon	N(1209)	N(1299)	N(1479)	N(1659)	N(1839)	N(1929)
$n_1n_2n_3$ (Eq. No.)	0,1,1 1,0,1 (67) 0,1,1 1,0,1 (69)	0,1,1 1,0,1 (51)	1,0,-1 0,1,-1 (67)	1,1,0 1,-1,0 (51) 1,0-1 -1,0,-1 (51)	1,-1,0 -1,1,0 (66) 0,2,0 2,0,0 (66)	-101,0-11 (66) 211,121 (66) 002,112 (67)
Theory	N(1209)#	⟵	N(1479)	2 N(1659)	2 N(1839)	2 N(1929)

Baryon	N(2019)	N(2199)	N(2379)	N(2549)	N(2559)	N(2649)*
$n_1n_2n_3$ (Eq. No)	1,1,2 1,-1,2 (51)	1,2,-1 2,1,-1 (66) -1,0,-1 0,-1,-1 (66)	2,0,0 -2,0,0 (51)	2, 1, -1 1, 2, -1 (69)	2, 2, 0 -1,-1,0 (67)	-112,1-12 (66) 202,022 (66) -121,2-11 (67)
Theory	N(2019)	2N(2199)	N(2379)	N(2549)	N(2559)	3N(2649)

see the following paragraph. * The next baryon N(2739) $\overrightarrow{n}$ = (1,±2,1), (2,±1,1), (2,0,±2), (0,±1,3) 4N(2739) in the Eq. (51).

From Table 2, we can see that the intrinsic quantum numbers of the theoretical results are the same as the experimental results. Also the theoretical masses of the baryons N and Δ are in very good agreement with the experimental results. The theoretical results $N(1209)$ is not found in experiments. We guess that it is covered up by the experimental baryon $\Delta(1232)$. The reasons are as follows : (1) they are unflavored baryons with the same S = C = b =0 and Q ($Q_{N^+} = Q_{\Delta^+}$ and $Q_{N^0} = Q_{\Delta^0}$); (2) they have the same $\overrightarrow{n}$ values ($\overrightarrow{n}_{N(1209)} = (011, 101)$, $\overrightarrow{n}_{\Delta(1299)}$ = (101,-101,011,0-11)) and they are both in the second **Brillouin zone**; (3) the experimental width (120 Mev) of $\Delta(1232)$ is very large, and the baryon $N(1209)$ is fall within the width region of $\Delta(1232)$; (4) the mass

(1209 Mev) of $N(1209)$ is essentially the same as the mass (1232 Mev) of $\Delta(1232)$. The experimental value 1232 is much lower than the theoretical value 1299 of $\Delta(1299)$ and the experimental width (120) is much larger than other baryons (with similar masses) support the explanation.

C The Strange Baryons Λ and Σ

The strange baryons Λ and Σ are compared in Table 3. The theoretical results of the baryons Λ are shown in the following list. In the list, we give all low mass possible baryons Λ with $\overrightarrow{n}$ values and the equation numbers in which the baryons are deduced. From the list, we can see that (1) $3\times\Lambda(1119)$ with $\overrightarrow{n}$ =110 and $2\times\Lambda(1209)$ with $\overrightarrow{n}$ =110 are the same baryon $\Lambda(1119)$. (2) $\Lambda(1929)$ with $\overrightarrow{n}$ =112 (see Eq. (61)) and $\Lambda(1929)$ with $\overrightarrow{n}$ =112 (see Eq. (69)) are the same baryon $\Lambda(1929)$. (3) However, $\Lambda(1299)$ with $\overrightarrow{n}$ = 002 and $\Lambda(1399)$ with $\overrightarrow{n}$ =002 are not the same baryon, because the baryon $\Lambda(1399)$ has a fluctuation energy $\Delta\varepsilon$ = 100 Mev (see Eq. (60)) but the baryon $\Lambda(1299)$ does not. (4) $\Lambda(1299)$ with $\overrightarrow{n}$ =002 and $\Lambda(1929)$ with $\overrightarrow{n}$ =002 (see Eq. (61)) are the same baryon $\Lambda(1299)$.

Baryon	$\Lambda(1119)$	$\Lambda(1209)$	$\Lambda(1299)$	$\Lambda(1399)$	$\Lambda(1659)$	$\Lambda(1929)$
$n_1n_2n_3$ (Eq. No)	1,1,0 (65) 1,1,0 (67) 1,1,0 (80)	1,1,0 (61) 1,1,0 (68)	0,0,2 (69)	0,0,2 (60)	0,1,-1 (61) 1,0,-1 (61) -1,-1,0 (61)	1,1,2 (61) 1,1,2 (69) 1,2,1 (70) 2,1,1 (70) 0,0,2 (61)
Theory	$\Lambda(1119)$		$\Lambda(1299)$	$\Lambda(1399)$	$3\Lambda(1659)$	$3\Lambda(1929)$

Baryon	$\Lambda(2019)$	$\Lambda(2359)$	$\Lambda(2379)$	$\Lambda(2559)$	$\Lambda(2649)$
$n_1n_2n_3$ (Eq. No)	-1,-1,2 (68) -1,-10 (69)	1,1,-2 (67)	0,0,-2 (61)	2,2,0 (65)	220 (61), 220(69) 121(71), 2-11(71) 1-12 (61),2-11(61) 0-1-1 (76)
Theory	$2\Lambda(2019)$	$\Lambda(2359)$	$\Lambda(2379)$	$\Lambda(2559)$	$5\Lambda(2649)$

All possible theoretical baryons Σ which have experimental results to compare with are shown in following list. From the list, we get that (1) the 3 asymmetry $\overrightarrow{n}$ values in the 5 possible $\Sigma(1929)$ are ignored; (2) similarly, the 3 asymmetry $\overrightarrow{n}$ values in the possible $\Sigma(2649)$ are ignored..

Baryon	$\Sigma(1209)$	$\Sigma(1299)$	$\Sigma(1659)$	$\Sigma(1929)$
	1,0,1	0,0,2	1-10,-110,01-1	020,002,200 (61)
	0,1,1	-1,0,1	0-11,10-1,-101	121,211,112 (61)
$n_1n_2n_3$	1,1,0	0,-1,1	-10-1,0-1-1,-1-10	112,1-10,-110 (69)
(Eq. No)	(61)	(69)	(61)	01-1,10-1,121 (70)
				020,200,211 (70)
Theory	$\Sigma(1209)$	$\Sigma(1299)$	3 $\Sigma(1659)$	2 $\Sigma(1929)$

Baryon	$\Sigma(2019)$	$\Sigma(2379)$	$\Sigma(2649)$	$\Sigma(2739)$
			1-12,-112,21-1 (61)	0-20,-200,-211
	-1,-1,0	0,-2,0	2-11,12-1,-121 (61)	1-21,013,103
$n_1n_2n_3$	1,1,2	-2,0,0	202,022,220 (61)	(72)
(Eq. No)	1,-1,2	0,0,-2	220,21-1,12-1 (69)	0-22,-202,-2-11
	(69)	(61)	220,022,-121 (71)	-1-21,0-13,-103
			2-11,0-1-1,-1,0,-1 (71)	(73)
Theory	$\Sigma(2019)$	$\Sigma(2379)$	$3\Sigma(2649)$	$4\Sigma(2739)$

Using Table 3, we can see that the theoretical masses of the baryons Λ and Σ are in very good agreement with the experimental results, and their theoretical and experimental intrinsic quantum numbers are the same.

D The Strange Baryons Ξ and Ω

The theoretical results of the baryons Ξ are deduced in the following list. In the list, $\overrightarrow{n}$ =101,10-1 $\Xi(1299)$ (80) and $\overrightarrow{n}$ =101,10-1 $\Xi(1479)$ (63) are the same baryon $\Xi(1299)$. $\overrightarrow{n}$ =011,01-1 $\Xi(1479)$ (63) and $\overrightarrow{n}$ =011,01-1 $\Xi(1479)$ (80) are the same baryon $\Xi(1479)$. $\overrightarrow{n}$ =0-11,0-1-1 $\Xi(1659)$ (63) and $\overrightarrow{n}$ =0-11,0-1-1 $\Xi(2019)$ (81) are the same baryon $\Xi(1659)$. $\overrightarrow{n}$ =211,21-1 $\Xi(2019)$ (81) and $\overrightarrow{n}$ =211,21-1 $\Xi(2199)$ (63) are the same baryon $\Xi(2019)$. $\overrightarrow{n}$ =002,00-2 $\Xi(2379)$ (62) and $\overrightarrow{n}$ =002,00-2 $\Xi(2559)$ (83) are the same baryon $\Xi(2379)$. $\overrightarrow{n}$ =112,11-2 $\Xi(2559)$ (62) and $\overrightarrow{n}$ =112,11-2 $\Xi(2559)$

(83) are the same baryon Ξ(2559). $\overrightarrow{n}$ =020,-110 Ξ(1839) (80) is ignored since the $\overrightarrow{n}$ value is asymmetry. $\overrightarrow{n}$ =310,2-20 Ξ(2739) (80) and $\overrightarrow{n}$ =310,2-20 (83) are ignored also.

Baryon	Ξ(1299)	Ξ(1479)	Ξ(1659)	Ξ(1839)	Ξ(1929)	Ξ(2019)
	101	101,10-1	1-10,-110	200,	121,	2-11,2-1-1
	10-1	(63)	(62)	020	211	(80)
$n_1n_2n_3$	(80)	011,01-1	-101,-10-1	(62)	(or)	0-11,0-1-1
(Eq. No)	200	(63)	(63)	020	01-1	(81)
	1-10	011,01-1	0-11,0-1-1	-110	10-1	211,21-1
	(80)	(80)	(63)	(80)	(75)	(81)
Theory	Ξ(1299)	Ξ(1479)	3 Ξ(1659)	Ξ(1839)	Ξ(1929)	2Ξ(2019)

Baryon	Ξ(2199)	Ξ(2379)	Ξ(2559)	Ξ(2739)
	-1 0 1,-1 0 -1		1,1,2;1,1,-2	310,2-20 (80)
	(81)	002,00-2	(62)	301,30-1 (81)
$n_1n_2n_3$	1 2 1, 1 2 -1	(62)	1,1,2;1,1,-2	1-21,1-2-1(81)
(Eq. No)	(63)(81)	-200,0-20	(83)	202,20-2 (83)
	2 1 1, 2 1 -1	(62)	0,0,2;0,0,-2	1-12,1-1-2 (83)
	(63)		(83)	310,0-20 (83)
				0-20,-200 (77)
Theory	2Ξ(2199)	Ξ(2379)	Ξ(2559)	5Ξ(2739)

The theoretical results of the baryons Ω are shown in the following list. Although Ω(1659) and Ω(2359) have the same $\overrightarrow{n} = (-1, -1, 0)$, they are not the same baryon, because Ω(2359) has a fluctuation energy $\Delta\varepsilon = -200$ Mev (see (82)), but the baryon Ω(1659) does not.

Baryon	Ω(1659)	Ω(2359)	Ω(2879)	Ω(3619)	Ω(7019)
$n_1n_2n_3$	$-1, -1, 0$	$-1, -1,$ 0	$-2,$ 0, 0	$-2, -2,$ 0	-3,-3,0
(Eq. No)	(65)	(83)	(83)	(65)	(65)

The theoretical intrinsic quantum numbers of the baryons Ξ and Ω are the same as the experimental results (see Table 4). The theoretical masses of the baryons Ξ and Ω

are in very good agreement with the experimental results.

E The Charmed and Bottom Baryons Λ_c^+ and Λ_b^0

The charmed and bottom baryons Λ_c^+ and Λ_b^0 can be found in Table 5. The theoretical results of the baryons $\Lambda_c^+$and Λ_b are listed below:

Baryon	$\Lambda_c^+(2279)$	$\Lambda_c^+(2449)$	$\Lambda_c^+(2539)$	$\Lambda_c^+(2759)$	$\Lambda_b(5639)$	$\Lambda_b(10159)$
$n_1n_2n_3$	0, 0, -2	-1,2,1 or2-11	0, -2, 2 or-202	0,0,-2	3, 3, 0	4, 4, 0
(Eq.No)	(60)	(76)	(78)	(67)	(65)	(65)
Theory	$\Lambda_c^+(2279)$	$\Lambda_c^+(2449)$	$\Lambda_c^+(2539)$	$\Lambda_c^+(2759)$	$\Lambda_b(5639)$	$\Lambda_b(10159)$

From the list, we can see that baryon $\Lambda_c^+(2759)$ and baryon $\Lambda_c^+(2279)$ are not the same baryon, since $\Lambda_c^+(2279)$ has $\Delta\varepsilon = -100$, while $\Lambda_c^+(2759)$ has $\Delta\varepsilon = 200$.

The theoretical intrinsic quantum numbers of the baryons Λ_c^+ and Λ_b^0 are the same as the experimental results. The experimental masses of the charmed baryons (Λ_c^+) and bottom baryons (Λ_b^0) are in very good agreement with the theoretical results as well.

F The Charmed Baryons Σ_c, Ξ_c and Ω_C

Finally, we compare the theoretical results with the experimental results for the charmed strange baryons Ω_C, Ξ_c and Σ_c in Table 6. Their intrinsic quantum numbers are all matched completely, and their masses are in very good agreement. The theoretical results of the baryons Σ_c, $\Xi_c$and Ω_c are listed below:

Baryon	$\Sigma_c(2449)$	$\Sigma_c(2539)$	$\Sigma_c(2969)$	$\Xi_c(2549)$	$\Xi_c(3169)$
$n_1n_2n_3$	2, 0, 2 0, 2, 2	0, -1, 3 -1, 0, 3	3, 0, 1 0, 3, 1	2, 0, 2 0, 2, 2	3, 0, 1 0, 3, 1
(Eq. No)	2, -1, 1 (76)	-2, 0, 2 (78)	2, 2, 2 (79)	(71)	(74)
Theory	$\Sigma_c(2449)$	$\Sigma_c(2539)$	$\Sigma_c(2969)$	$\Xi_c(2549)$	$\Xi_c(3169)$

Baryon	$\Omega_c(2759)$	$\Omega_c(3679)$
$n_1n_2n_3$	2, 2, 0	1 3 0 or -200
(Eq. No)	(82)	(83)
Theory	$\Omega_c(2759)$	$\Omega_c(3679)$

In summary, the BCC model explains all baryon experimental intrinsic quantum numbers and masses. Virtually no experimentally confirmed baryon is not included in the model.

It is worth while to pay attention to the **experimental top limits** of the baryons. According to the BCC model, a series of possible baryons exist. However, when energy goes higher and higher, on one hand, the theoretical energy bands (baryons) will become denser and denser (such as: there are 5 $\Delta(2739)$, 3 N(2649), 4 N(2739), 5 $\Lambda(2649)$, 3 $\Sigma(2649)$, 4 $\Sigma(2739)$, and 5 $\Xi(2739)$ in mass 2645 Mev-2745 Mev); while on the other hand, the experimental full widthes of the baryons will become wider and wider (such as Γ=650 Mev of N(2600), Γ=400 Mev of $\Delta(2420)$, Γ=150 Mev of $\Lambda(2350)$, and Γ=100 Mev of $\Sigma(2250)$...). making them extremely difficult to be separated. Therefore, currently it is very difficult to discover higher energy baryons predicted by the BCC model. We believe that many new baryons will be discovered in the future with the development of more sensitive experimental techniques.

VI Predictions and Discussion

A Some New Baryons

The following new baryons predicted by the model seem to have a better chance to be discovered in a not too distant future

$$\begin{array}{llllll}
I=0 & S=-3 & Q=-1 & \Omega^-(3619) & & (65)\\
I=0 & b=-1 & Q=0 & \Lambda_b^0(10159) & & (65)\\
I=0 & C=+1 & Q=+1 & \Lambda_C^+(6599) & & (60)\\
I=0 & S=-1 & Q=0 & \Lambda^0(2559) & & (65)\\
I=1/2 & S=-1 & C=+1 & Q=1,0 & \Xi_C(3169) & (74)\\
I=1 & S=-1 & C=+1 & Q=2,1,0 & \Sigma_C(2969) & (79)
\end{array} \tag{84}$$

In the last column, we give the equation number where the baryons are first deduced in this paper.

B The Super Heavy Electron Spectrum

Similar to the energy bands of the Lee Particle, we can also deduce the energy bands for the Thomson [36] particle (a vacuum state electron). When a Thomson particle is in the vacuum state the lepton number $L = 0$, but when it is excited from vacuum, the lepton number $L = 1$. The energy $\varepsilon^{(0)}(\vec{k}, \vec{n})$ of the excited Thomson particle are determined (similarly to (17)) by

$$\varepsilon^{(0)}(\vec{k}, \vec{n}) = V_{Th} + C_{Th}E(\vec{k}, \vec{n}), \tag{85}$$

where

$$C_{Th} = h^2/(2m_{Th}a_x^2). \tag{86}$$

It is easy to determine the constant V_{Th}. From Eq.(85) we can see that the lowest energy is $\varepsilon^{(0)}(\vec{k}, \vec{n}) = V_{Th}$. Similar to (38), we know that the lowest energy is the mass of the electron (0.511 Mev), so

$$V_{Th} = m_e = 0.511 \text{ Mev}. \tag{87}$$

In order to determine the parameter C_{Th}, we assume that the masses of the Thomson particle and the Lee Particle are proportional to the masses of the ground states of the excited Thomson particle (the electron) and the excited Lee Particle (the proton and the neutron):

$$m_{Lee} = cm_N \quad , \tag{88}$$

$$m_{Th} = cm_e \quad . \tag{89}$$

Thus

$$m_{Th} = cm_e = (m_{Lee}/m_N)m_e \quad . \tag{90}$$

Using (39), (86), (87), and (90), we get

$$C_{Th} = \frac{h^2}{2m_{Th}a_x^2} = \frac{m_N}{m_e}\frac{h^2}{2m_{Lee}a_x^2} = \frac{939}{0.511}360\text{Mev} = 662\text{Gev}. \tag{91}$$

Hence

$$\varepsilon^{(0)}(\vec{k},\vec{n}) = V_{Th} + C_{Th}E(\vec{k},\vec{n}) = [0.511\times 10^{-3} + 662\times E(\vec{k},\vec{n})]\text{Gev}. \tag{92}$$

Fig. 2-4 show the energy bands of the body center cubic periodic field. The periodic field is a strong interaction field which originates from the Lee Particles. Because the Thomson particles (the vacuum state electrons) do not have any strong interactions, they can not see the body center cubic periodic field. They can see, however, a simple cubic electromagnetic periodic field which originates from the charged Lee Particles (the point aproximation of the colorless group uud). Similar to Fig. 2-4, we can find the energy bands of the simple cubic periodic field. Since the isospin, strange number, charmed number, and bottom number of the leptons have not been observed in the experiments, we do have left them out. We provide the electric charge and mass for a few lower energy excited states of the Thomson particle, as the touchstone of the BCC

model. The electric charges are all the same with the Thomson particle. If they are really discovered, the conjecture of the BCC model of the vacuum material is somehow confirmed.

$E(\vec{k},\vec{n})$	0	1/4	1/2	3/4	1	2
Theory(Gev)	e^-(0.511 Mev)	E(166)	E(331)	E(497)	E(662)	E(1324)
Expt. (Gev)	e^-(0.511 Mev)	E(167)				
ΔM/M	0.000	0.006				

We would like to call the excited Thomson particle super heavy electrons with symbole E according to T. D. Lee in his book [37]. Among them, E(331 Gev), E(497 Gev), E(662 Gev) and E(1324 Gev) have not been discovered yet. The reason is that their energies are too high. However, a particle with a mass of 167 Gev has been found by the experimentt recently[38]. It might be the super heavy electron E(166), which is about 177 times heavier than a proton.

C Experimental Verification of the BCC Model

1. From (65) and Fig. 5 (c), we see three "brother" baryons: at $E_N = 1/2$ $\overrightarrow{n} = (1,1,0)$ $\Lambda(1119)$, at $E_N = 9/2$ $\overrightarrow{n} = (2,2,0)$ $\Lambda(2559)$, at $E_N = 25/2$ $\overrightarrow{n} = (3,3,0)$ $\Lambda_b(5639)$. They are born on the same symmetry axis Σ and at the same symmetry point N. The three "brothers" have the same isospin I = 0, the same electric charge Q = 0, and the same generalized strange number (see (11)) S_G = S + C + b = -1. Among the three "brothers", the light one ($\Lambda(1119)$) and the heavy one ($\Lambda_b(5639)$) both have long lifetimes ($\tau = 2.6\times10^{-10}s$ for $\Lambda(1119)$, $\tau = 1.1\times10^{-12}s$ for $\Lambda_b(5639)$), but the middle one ($\Lambda(2559)$) has not been discovered. Thus, we propose that one search for the long lifetime baryon $\Lambda(2559)$ (I = 0, S = -1, Q = 0, M = 2559 Mev, and lifetime $2.6\times10^{-10}s > \tau > 1.1\times10^{-12}s$). The discovery of the baryon $\Lambda(2559)$ will provide a strong support for the BCC model.

2. According to the BCC model, the excited Lee particles which are in different energy band states form a baryon spectrum. Similarly, the excited Thomson [36] particles shall form a super heavy electron spectrum. if we real experimentally observe the spectrum, we will confirm the BCC model, and confirm the body center cubic symmetry of the vacuum material. **It will be a great discovery in the history of physics**. Therefore, we suggest that one search experimentally for the super heavy electron spectrum. The lowest super heavy electron of the spectrum may have already been discovered [20] [38].

D Discussions

1. From (39), we have

$$m_b a_x^2 = h^2/720 \text{ Mev.} \tag{93}$$

Although we do not know the values of m_b and a_x, we find that $m_b a_x^2$ is a constant. According to the renormalization theory [26], the bare mass of the Lee Particle should be infinite, so that a_x will be zero. Of course, the infinite and the zero are physical concepts in this case. We understand that the "infinite" means m_b is huge and the "zero" means a_x is much smaller than the nuclear radius. "m_b is huge" guarantees that we can use the Schrödinger equation (13) instead of the Dirac equation, and "a_x is much smaller than the nuclear radius" makes the structure of the vacuum material very difficult to be discovered.

2. In a sense, the vacuum material with the body center cubic structure works like an ultra-superconductor. There is no electric and mechanical resistance to any particle and any physical body (with or without electric charge) moving inside the vacuum material. Since the energy gaps are so large (for electron the energy gap is about 0.5 Mev; for proton and neutron the energy gap is about 939 Mev), the vacuum

remains unchanged when a physical body is moving with a constant velocity. At the same time, the motion of the physical body remains unchanged also.

3. The BCC model presents not only a baryon spectrum, but also a natural and reasonable explanation for the experimental fact that all baryons automatically decay to nucleons (p or n) in a very short time ($< 10^{-9}$ second). Although the decay forms are various, all baryons must decay to the same kind of particles - nucleons. There is no baryon that does not decay, and there is no baryon that decays into other particle. The reason is very simple: the baryons are energy band excited states of the Lee Particle, while the nucleons are the ground band states of the Lee Particles. It is a well known law in physics that the excited states will decay into the ground state. Thus, the long life baryons $\Lambda(1116)$, $\Sigma(1193)$, $\Xi(1318)$, $\Omega(1672)$, $\Lambda_c(2285)$, $\Lambda_b(5641)$...may be the metastable states of the Lee Particles.

4. Since the theoretical baryon mass spectrum of the free particle approximation ($V(\vec{r}) = V_o$ and the wave functions satisfy the body center cubic periodic symmetries) is very close to the experimental mass spectrum, the amplitude (A) of the strong interaction periodic field should be much smaller than the average of the periodic field (V_0). According the BCC model, Dirac's sea concept[15] is a complete free approximation for the vacuum periodic field ($V(\vec{r}) = V_o$ and the wave functions do not have to satisfy the body center cubic periodic symmetries). Because the amplitude of the vacuum periodic field is very small and the periodic constant a_x is very small also, Dirac's sea concept is a very good approximation. In fact, Dirac's sea concept has deeply embedded in quantum field theory and the Standard Model.

VII Conclusions

1. Although baryons (Δ, N, Λ, Σ, Ξ, Ω, Λ_C, Ξ_C, Σ_C, and Λ_b...) are so different from one another in I, S, C, b, Q, and M, they may be the same kind of particles (the Lee Particles), which are in different energy band states. The long life baryons $\Lambda(1116)$, $\Sigma(1193)$, $\Omega(1672)$, ... may be the metastable states. The conclusion is supported not only by the results of the BCC model, but also by many experiments which demonstrate that all baryons (their lives are very short, $\tau < 10^{-9}$ sec.) decay to the same kind of particles - nucleons (the ground energy bands).

2. The BCC model has deduced the strange number S, the charmed number C, and the bottom number b from the symmetry of body center cubic periodic field. It means that the quantum number S, C, and b may be not from the quarks (s, c, b), they may be from new symmetries. Frank Wilczek point out in Review of Modern Physics [39]: Some "appropriate symmetry principles and degrees of freedom, in terms of which the theory should be formulated, have not yet been identified." We believe that the body center cubic periodic symmetry of the vacuum material may be the appropriate symmetry.

3. The BCC model has shown that there may be only 2 kinds of quarks (u and d), each of them has three colored members, in the quark family. The super-strong attractive forces (color) make the colorless Lee Particle (uud and udd). The Lee Particles constitute a body center cubic lattice in the vacuum. In other words, the vacuum materials has body center cubic symmetry.

4. Due to the existence of the vacuum material, all observable particles are constantly affected by the vacuum material (the Lee Particle lattice). Thus, some laws of statistics (such as fluctuation) can not be ignored.

5. Although the BCC model successfully explain the baryon spectrum, the baryon spectrum is deduced from 5 phenomenological Hypotheses and 3 phenomenological formulas in the BCC model. Thus, the BCC model is only a phenomenological model.

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[13] (1) T. D. Lee has pointed out that vacuum is the source of asymmetry in his book (*Particle Physics and Introduction to Field Theory, 1981, page* 378); furthermore, in the section "the possibility of vacuum engineering" of his book , T. D. Lee pointed out: "we believe our vacuum, ..., to be quite complicated. Like any other physical medium, it can carry long-range-order parameters and it may also undergo phase transitions... ". His ideas inspired us to research the structure of the vacuum. (2) T. D. Lee has pointed out: "We are still in the transition period. In order to apply the present theories, we need about seventeen ad hoc parameters. All these theories are based on symmetry considerations, yet most of the symmetry quantum numbers do not appear to be conserved. All hadrons are made of quarks and yet no single quark can be individually observed. ... We are in a serious dilemma about how to make the next giant step. Because the challenge is related to the very foundation of the totality of physics, a breakthrough is bound to bring us a profound change

in basic science." His statements strengthen our confidence in the research. (3) We thank T. D. Lee for his *particle physics* class in Beijing and his CUSPEA program which gave me an opportunity to get my Ph. D. in the U. S. A. (4) Lee is both a Chinese and an American name. Lee is the largest chinese family name and it may be the largest family name in the world. We use it to name the particles in order to represent ordinary people also. The vacuum particle in the particle world can not been seen directly just like ordinary people can not been seen in human history. Ordinary people (represented by the name Lee) form the social base. Similarly, the Lee Particles form the base of the perfect material universe.

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FIGURES

Fig. 1. The first Brillouin zone of the body center cubic lattice. The the symmetry points and axes are indicated. The center of the first Brillouin zone is at the point Γ. The axis Δ (the axis Γ-H) is a 4 fold rotation axis, the strange number S = 0, the baryon family Δ (Δ^{++}, Δ^{+}, Δ^{0}, Δ^{-}) will appear on the axis. The axes Λ (the axis Γ-P) and F (the axis P-H) are 3 fold rotation axes, the strange number S = -1, the baryon family Σ (Σ^{+}, Σ^{0}, Σ^{-}) will appear on the axes. The axes Σ (the axis Γ-N) and G (the axis M-N) are 2 fold rotation axes, the strange number S = -2, the baryon family Ξ (Ξ^{0}, Ξ^{-}) will appear on the axes. The axis D (the axis P-N) is parallel to the axis Δ, S = 0. And the axis is a 2 fold rotation axis, the baryon family N (N^{+}, N^{0}) will be on the axis.

Fig. 2. (a) The energy bands on the axis Δ (the axis $\Gamma-$H). The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the degeneracy. E_Γ is the value of $E(\vec{k}, \vec{n})$ (see Eq. (19)) at the end point Γ, while E_H is the value of $E(\vec{k}, \vec{n})$ at other end point H. (b) The energy bands on the axis Λ (the axis Γ-P). E_Γ is the value of $E(\vec{k}, \vec{n})$ (see Eq. (19)) at the end point Γ, while E_P is the value of $E(\vec{k}, \vec{n})$ at other end point P. The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the degeneracy.

Fig. 3. (a) The energy bands on the axis Σ (the axis Γ-N). The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the degeneracy. E_Γ is the value of $E(\vec{k}, \vec{n})$ (see Eq. (19)) at the end point Γ, while E_N is the value of $E(\vec{k}, \vec{n})$ at other end point N. (b) The energy bands on the axis D (the axis P-N). E_P is the value of $E(\vec{k}, \vec{n})$ (see Eq. (19)) at the end point P, while E_N is the value of $E(\vec{k}, \vec{n})$ at other end point N. The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the degeneracy.

Fig. 4. (a) The energy bands on the axis F (the axis P-H). The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the degeneracy. E_P is the value of $E(\vec{k}, \vec{n})$ (see Eq. (19)) at the end point P, while E_H is the value of $E(\vec{k}, \vec{n})$ at other end point H. (b) The energy bands on the axis G (the axis M-N). E_M is the value of $E(\vec{k}, \vec{n})$ (see Eq. (19)) at the end point M, while E_N is the value of $E(\vec{k}, \vec{n})$ at other end point N. The numbers above the lines are the values of $\vec{n} = (n_1, n_2, n_3)$. The numbers under the lines are the fold numbers of the degeneracy.

Fig. 5. (a) The 4 fold degenerate energy bands (selected from Fig. 2(a)) on the axis Δ (the axis Γ-H). The numbers above the lines are the values of $\vec{n}$ (n_1, n_2, n_3). The numbers under the lines are the numbers of the degeneracy of the energy bands. (b) The single energy bands (selected from Fig. 2(a)) on the axis Δ (the axis Γ-H). The numbers above the lines are the values of $\vec{n}$ (n_1, n_2, n_3). (c) The single energy band (selected from Fig. 3(a)) on the axis Σ (the axis Γ-N). The numbers above the lines are the values of $\vec{n}$ (n_1, n_2, n_3)

TABLE

Table 1. The Ground States of the Various Baryons.

Theory	Quantum. No		Experiment	R	Life Time
Name(M)	S, C, b, I, Q	Eq. No	Name(M)		
p(939)	0, 0, 0, 1/2, 1	(41)	p(938)	0.1	$> 10^{31} years$
n(939)	0, 0, 0, 1/2, 0	(41)	n(940)	0.1	1.0×10^{8} s
$\Lambda(1119)$	-1, 0, 0, 0, 0	(65)	$\Lambda(1116)$	0.3	$2.6\times10^{-10}s$
$\Sigma(1209)^{+}$	-1, 0, 0, 1, 1	(61)	$\Sigma(1189)^{+}$	1.7	$.80\times10^{-10}s$
$\Sigma(1209)^{0}$	-1, 0, 0, 1, 0	(61)	$\Sigma(1193)^{0}$	1.4	$7.4\times10^{-20}s$
$\Sigma(1209)^{-}$	-1, 0, 0, 1, -1	(61)	$\Sigma(1197)^{-}$	1.0	$1.5\times10^{-10}s$
$\Xi(1299)^{0}$	-2, 0, 0, 1/2, 0	(80)	$\Xi(1315)^{0}$	1.2	$2.9\times10^{-10}s$
$\Xi(1299)^{-}$	-2, 0, 0, 1/2, -1	(80)	$\Xi(1321)^{-}$	1.7	$1.6\times10^{-10}s$
$\Omega(1659)^{-}$	-3, 0, 0. 0, -1	(65)	$\Omega(1672)^{-}$	0.8	$.82\times10^{-10}s$
$\Lambda_c^{+}(2279)$	0, 1, 0, 0, 1	(60)	$\Lambda_c^{+}(2285)$	0.3	$.21\times10^{-12}s$
$\Xi_c^{+}(2549)$	-1, 1, 0, 1/2, 1	(71)	$\Xi_c^{+}(2466)$	3.4	$.35\times10^{-12}$
$\Xi_c^{0}(2549)$	-1, 1, 0, 1/2, 1	(71)	$\Xi_c^{0}(2470)$	3.2	$.10\times10^{-12}s$
$\Sigma_c^{++}(2449)$	0, 1, 0, 1, 2	(76)	$\Sigma_c^{++}(2453)$	0.2	
$\Sigma_c^{+}(2449)$	0, 1, 0, 1, 1	(76)	$\Sigma_c^{+}(2454)$	0.2	
$\Sigma_c^{0}(2449)$	0, 1, 0, 1, 0	(76)	$\Sigma_c^{0}(2452)$	0.1	
$\Omega_c(2759)$	0, 0, -1, 0, 0	(82)	$\Omega_c(2704)$	2.0	$.64\times10^{-13}s$
$\Lambda_b(5639)$	0, 0, -1, 0, 0	(65)	$\Lambda_b(5641)$	.04	$1.1\times10^{-12}s$
$\Delta(1299)^{++}$	0, 0, 0, 3/2, 2	(51)	$\Delta(1232)^{++}$	5.2	Γ=120 Mev
$\Delta(1299)^{+}$	0, 0, 0, 3/2, 1	(51)	$\Delta(1232)^{+}$	5.4	Γ=120 Mev
$\Delta(1299)^{0}$	0, 0, 0, 3/2, 0	(51)	$\Delta(1232)^{0}$	5.4	Γ=120 Mev
$\Delta(1299)^{-}$	0, 0, 0, 3/2, -1	(51)	$\Delta(1232)^{-}$	5.4	Γ=120 Mev

* In the third column, we give the equation number where the baryon can be found in this paper. In the fifth column, R $=(\frac{\Delta M}{M})\%$.

Table 2. The Unflavored Baryons N and Δ (S= C=b = 0)

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\bar{\mathbf{N}}(\mathbf{939})$	$\bar{\mathbf{N}}(\mathbf{939})$	**0.0**	$\bar{\Delta}(\mathbf{1254})^{\#}$	$\bar{\Delta}(\mathbf{1232})$	**1.8**
$N(1479)$	$N(1440)$ $N(1520)$ $N(1535)$				
$\bar{\mathbf{N}}(\mathbf{1479})$	$\bar{\mathbf{N}}(\mathbf{1498})$	**1.2**			
$N(1659)$ $N(1659)$	$N(1650)$ $N(1675)$ $N(1680)$ $N(1700)$ $N(1710)$ $N(1720)$		$\Delta(1659)$ $\Delta(1659)$	$\Delta(1600)$ $\Delta(1620)$ $\Delta(1700)$	
$\bar{\mathbf{N}}(\mathbf{1659})$	$\bar{\mathbf{N}}(\mathbf{1689})$	**1.7**	$\bar{\Delta}(\mathbf{1659})$	$\bar{\Delta}(\mathbf{1640})$	**1.2**
$N(1839)$ $N(1839)$ $N(1929)$ $N(1929)$ $N(2019)$	$N(1900)*$ $N(1990)*$ $N(2000)*$ $N(2080)*$		$\Delta(1929)$ $\Delta(1929)$ $\Delta(2019)$	$\Delta(1900)$ $\Delta(1905)$ $\Delta(1910)$ $\Delta(1920)$ $\Delta(1930)$ $\Delta(1950)$	
$\bar{\mathbf{N}}(\mathbf{1914})$	$\bar{\mathbf{N}}(\mathbf{1923})$	**0.5**	$\bar{\Delta}(\mathbf{1959})$	$\bar{\Delta}(\mathbf{1919})$	**2.1**
$N(2199)$ $N(2199)$	$N(2190)$ $N(2220)$ $N(2250)$				
$\bar{\mathbf{N}}(\mathbf{2199})$	$\bar{\mathbf{N}}(\mathbf{2220})$	**0.9**			
$N(2379)$ $N(2549)$			$\Delta(2379)$	$\Delta(2420)$	
$N(2549)$ $N(2559)$			$\bar{\Delta}(\mathbf{2379})$	$\bar{\Delta}(\mathbf{2420})$	**1.6**
$\mathbf{3N}(\mathbf{2649})$	$\mathbf{N}(\mathbf{2600})$	**1.9**	$\Delta(2649)$		
$4N(2739)$			$5\Delta(2739)$		

#The average of N(1209) and $\Delta(1299)$.

*Evidences are fair, they are not listed in the Baryon Summary Table [10].

Table 3. Two Kinds of Strange Baryons Λ and Σ ($S = -1$)

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Lambda(\mathbf{1119})$	$\Lambda(\mathbf{1116})$	**0.36**	$\Sigma(\mathbf{1209})$	$\Sigma(\mathbf{1193})$	**1.4**
$\Lambda(1299)$ $\Lambda(1399)$					
$\overline{\Lambda}(\mathbf{1349})$	$\overline{\Lambda}(\mathbf{1405})$	**4.0**	$\Sigma(\mathbf{1299})$	$\Sigma(\mathbf{1385})$	**6.2**
$\Lambda(1659)$ $\Lambda(1659)$ $\Lambda(1659)$	$\Lambda(1520)$ $\Lambda(1600)$ $\Lambda(1670)$ $\Lambda(1690)$		$\Sigma(1659)$ $\Sigma(1659)$ $\Sigma(1659)$	$\Sigma(1660)$ $\Sigma(1670)$ $\Sigma(1750)$ $\Sigma(1775)$	
$\bar{\Lambda}(\mathbf{1659})$	$\bar{\Lambda}(\mathbf{1620})$	**2.4**	$\bar{\Sigma}(\mathbf{1659})$	$\bar{\Sigma}(\mathbf{1714})$	**3.2**
$\Lambda(1929)$ $\Lambda(1929)$ $\Lambda(1929)$	$\Lambda(1800)$ $\Lambda(1810)$ $\Lambda(1820)$ $\Lambda(1830)$ $\Lambda(1890)$		$\Sigma(1929)$ $\Sigma(1929)$	$\Sigma(1915)$ $\Sigma(1939)$	
$\bar{\Lambda}(\mathbf{1929})$	$\bar{\Lambda}(\mathbf{1830})$	**5.4**	$\bar{\Sigma}(\mathbf{1929})$	$\bar{\Sigma}(\mathbf{1928})$	**.05**
$\Lambda(2019)$ $\Lambda(2019)$	$\Lambda(2100)$ $\Lambda(2110)$		$\Sigma(\mathbf{2019})$	$\Sigma(\mathbf{2030})$	**.54**
$\bar{\Lambda}(\mathbf{2019})$	$\Lambda(\mathbf{2105})$	**4.1**			
$\Lambda(2359)$ $\Lambda(2379)$	$\Lambda(2350)$		$\Sigma(2379)$	$\Sigma(2250)$ $\Sigma(2455)^*$	
$\bar{\Lambda}(\mathbf{2369})$	$\bar{\Lambda}(\mathbf{2350})$	**0.8**	$\bar{\Sigma}(\mathbf{2379})$	$\bar{\Sigma}(\mathbf{2353})$	**1.1**
$\Lambda(\mathbf{2559})$	$\Lambda(\mathbf{2585})^*$	**0.9**			
$5\Lambda(2649)$			**3** $\Sigma(\mathbf{2649})$	$\Sigma(\mathbf{2620})$	**1.1**
			4 $\Sigma(\mathbf{2739})$		

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [10].

Table 4. The Baryons Ξ and the Baryons Ω

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Xi(\mathbf{1299})$	$\Xi(\mathbf{1318})$	**1.5**	$\Omega(\mathbf{1659})$	$\Omega(\mathbf{1672})$	**0.8**
$\Xi(\mathbf{1479})$	$\Xi(\mathbf{1530})$	**3.3**	$\Omega(2359)$	$\Omega(2250)$ $\Omega(2380)$ $\Omega(2470)$	
$\mathbf{3}\Xi(\mathbf{1659})$	$\Xi(\mathbf{1690})$	**1.8**	$\bar{\Omega}(\mathbf{2359})$	$\bar{\Omega}(\mathbf{2367})$	**0.4**
$\Xi(\mathbf{1839})$	$\Xi(\mathbf{1820})$	**1.1**	$\Omega(2879)$		
$\Xi(\mathbf{1929})$	$\Xi(\mathbf{1950})$	**1.1**	$\Omega(3619)$		
$\mathbf{2}\Xi(\mathbf{2019})$	$\Xi(\mathbf{2030})$	**1.0**	$\Omega(7019)$		
$\mathbf{2}\Xi(\mathbf{2199})$	$\Xi(\mathbf{2250})^*$	**2.3**			
$\Xi(\mathbf{2379})$	$\Xi(\mathbf{2370})^*$	**0.4**			
$\Xi(2559)$					
$5\Xi(2739)$					

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [10].

Table 5. Charmed Λ_c^+ and Bottom Λ_b^0 Baryons

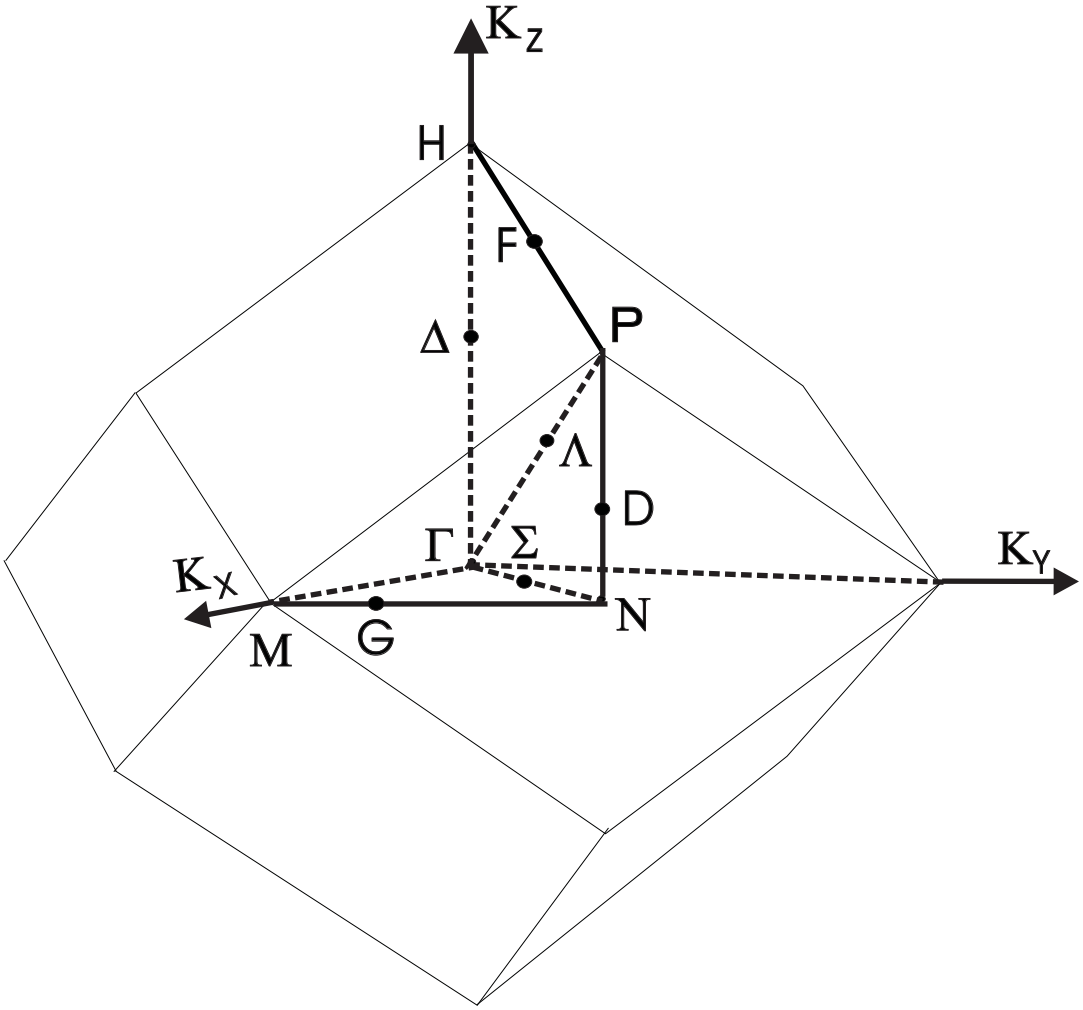
Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Lambda_c^+(\mathbf{2279})$	$\Lambda_c^+(\mathbf{2285})$	**0.22**	$\Lambda_b^0(\mathbf{5639})$	$\Lambda_b^0(\mathbf{5641})$	0.035
$\Lambda_c^+(2449)$ $\Lambda_c^+(2539)$	$\Lambda_c^+(2593)$ $\Lambda_c^+(2625)$		$\Lambda_b^0(10159)$		
$\bar{\Lambda}_c^+(\mathbf{2494})$	$\bar{\Lambda}_c^+(\mathbf{2609})$	**4.4**			
$\Lambda_c^+(2759)$					
$\Lambda_c^+(2969)$					
$\Lambda_c^+(6599)$					

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [10].

Table 6. Charmed Strange Baryon Ξ_c, Σ_c and Ω_C

Theory	Experiment	$\frac{\Delta M}{M}\%$	Theory	Experiment	$\frac{\Delta M}{M}\%$
$\Xi_c(2549)$	$\Xi_c(2468)$ $\Xi_c(2645)$		$\Sigma_c(2449)$ $\Sigma_c(2539)$	$\Sigma_c(2455)$ $\Sigma_c(2530)*$	
$\bar{\Xi}_c(\mathbf{2549})$	$\bar{\Xi}_c(\mathbf{2557})$	**0.3**	$\bar{\Sigma}_c(\mathbf{2495})$	$\bar{\Sigma}_c(\mathbf{2493})$	**0.08**
$\Xi_C(3169)$			$\Sigma_c(2969)$		
			$\Omega_C(\mathbf{2759})$	$\Omega_C(\mathbf{2704})$	**2.0**
			$\Omega_C(3679)$		

*Evidences of existence for these baryons are only fair, they are not listed in the Baryon Summary Table [10].

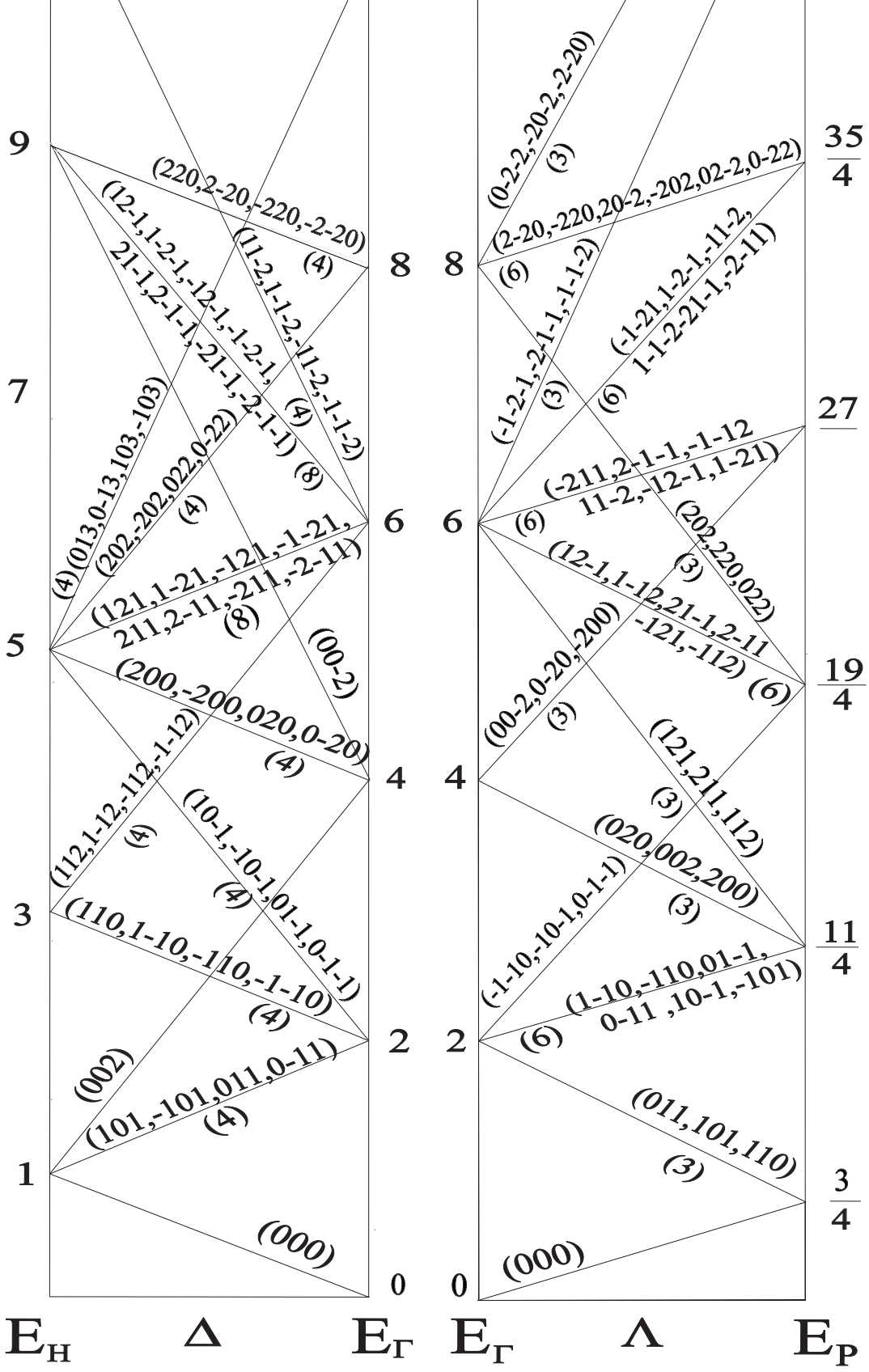


■ The axis Δ (the axis Γ-H) is a four fold rotation axis

▲ The axis Λ(the axis Γ-P) is a three fold rotation axis

⬮ The axis Σ (the axis Γ-N) is a two fold rotation axis

Figure 1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1
8
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(8)
(11-2,1-1-2,11-2,-1-1-2)
(4)
(4)(013,0-13,103,-103)
(202,-202,022,0-22)
(4)
(121,1-21,-121,-1-21,
211,2-11,-211,-2-11)
(8)
(00-2)
(200,-200,020,0-20)
(4)
(112,1-12,-112,-1-12)
(4)
(10-1,-10-1,01-1,0-1-1)
(4)
(110,1-10,-110,-1-10)
(4)
(002)
(101,-101,011,0-11)
(4)
(000)
E_H
Δ
$E_Г$
(a)
8
6
4
2
0
$\frac{35}{4}$
$\frac{27}{4}$
$\frac{19}{4}$
$\frac{11}{4}$
$\frac{3}{4}$
(0-2-2,-20-2,-2-20)
(3)
(2-20,-220,20-2,-202,02-2,0-22)
(6)
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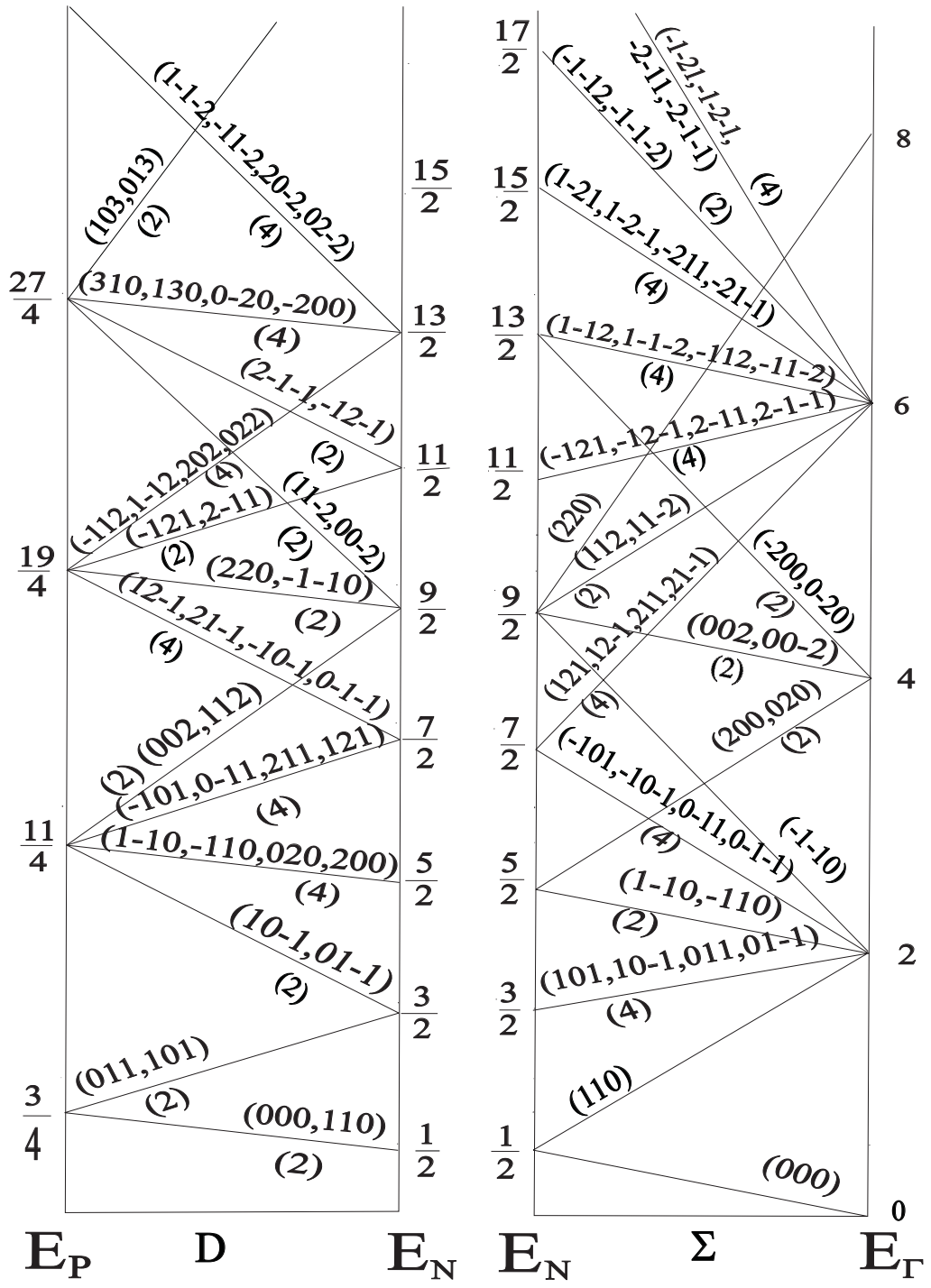
(3)
(-1-21,1-2-1,-11-2,
1-1-2-21-1,-2-11)
(6)
(-211,2-1-1,-1-12
11-2,-12-1,1-21)
(6)
(202,220,022)
(3)
(12-1,1-12,21-1,2-11
-121,-112)
(6)
(00-2,0-20,-200)
(3)
(121,211,112)
(3)
(020,002,200)
(3)
(-1-10,-10-1,0-1-1)
(1-10,-110,01-1,
0-11 ,10-1,-101)
(6)
(011,101,110)
(3)
(000)
$E_Г$
Λ
E_P
(b)

Figure 2


27/4
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11/4
3/4
15/2
13/2
11/2
9/2
7/2
5/2
3/2
1/2
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(103,013)
(2)
(4)
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(4)
(2-1-1,-12-1)
(2)
(4)
(-112,1-12,202,022)
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(2)
(11-2,00-2)
(2)
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(2)
(12-1,21-1,-10-1,0-1-1)
(4)
(2) (002,112)
(-101,0-11,211,121)
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(1-10,-110,020,200)
(4)
(10-1,01-1)
(2)
(011,101)
(2)
(000,110)
(2)
E_P
D
E_N
(b)
17/2
15/2
13/2
11/2
9/2
7/2
5/2
3/2
1/2
8
6
4
2
0
(-1-21,-1-2-1,
-2-11,-2-1-1)
(-1-12,-1-1-2)
(2)
(4)
(1-21,1-2-1,-211,-21-1)
(4)
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(4)
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(4)
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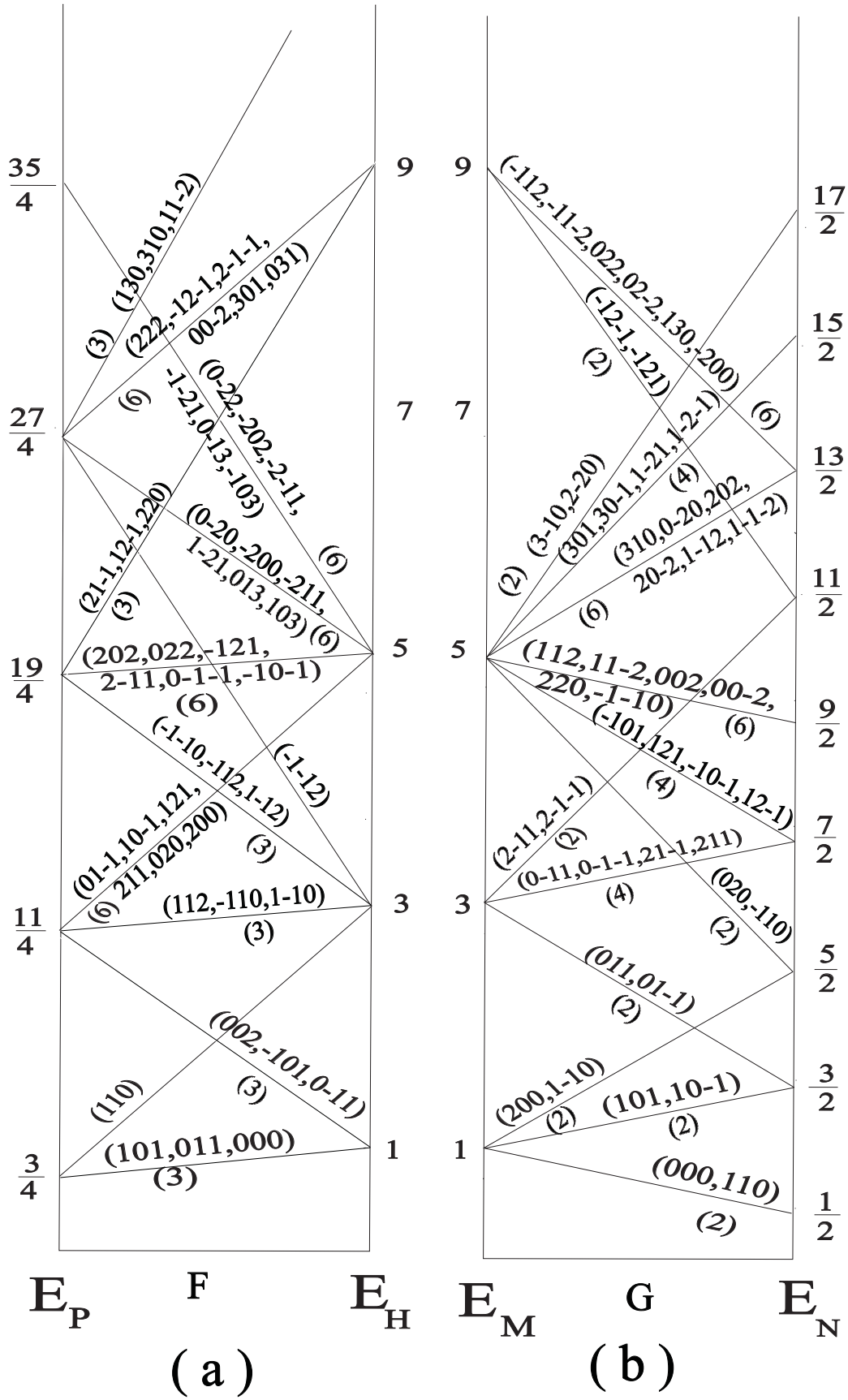
(112,11-2)
(2)
(-200,0-20)
(2)
(121,12-1,211,21-1)
(4)
(002,00-2)
(2)
(200,020)
(2)
(-101,-10-1,0-11,0-1-1)
(4)
(-1-10)
(1-10,-110)
(2)
(101,10-1,011,01-1)
(4)
(110)
(000)
E_N
Σ
E_Γ
(a)

Figure 3


35/4
27/4
19/4
11/4
3/4
9
7
5
3
1
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00-2,301,031)
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(0-22,-202,-2-11,
(6)
(21-1,12-1,220)
(3)
(0-20,-200,-211,
1-21,013,103) (6)
(202,022,-121,
2-11,0-1-1,-10-1)
(6)
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(-1-12)
(01-1,10-1,121,
211,020,200)
(6)
(3)
(112,-110,1-10)
(3)
(002,-101,0-11)
(110)
(3)
(101,011,000)
(3)
E_P
F
E_H
(a)
9
7
5
3
1
17/2
15/2
13/2
11/2
9/2
7/2
5/2
3/2
1/2
(-112,-11-2,022,02-2,130,-200)
(-12-1,-121)
(2)
(6)
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(2)
(301,30-1,1-21,1-2-1)
(4)
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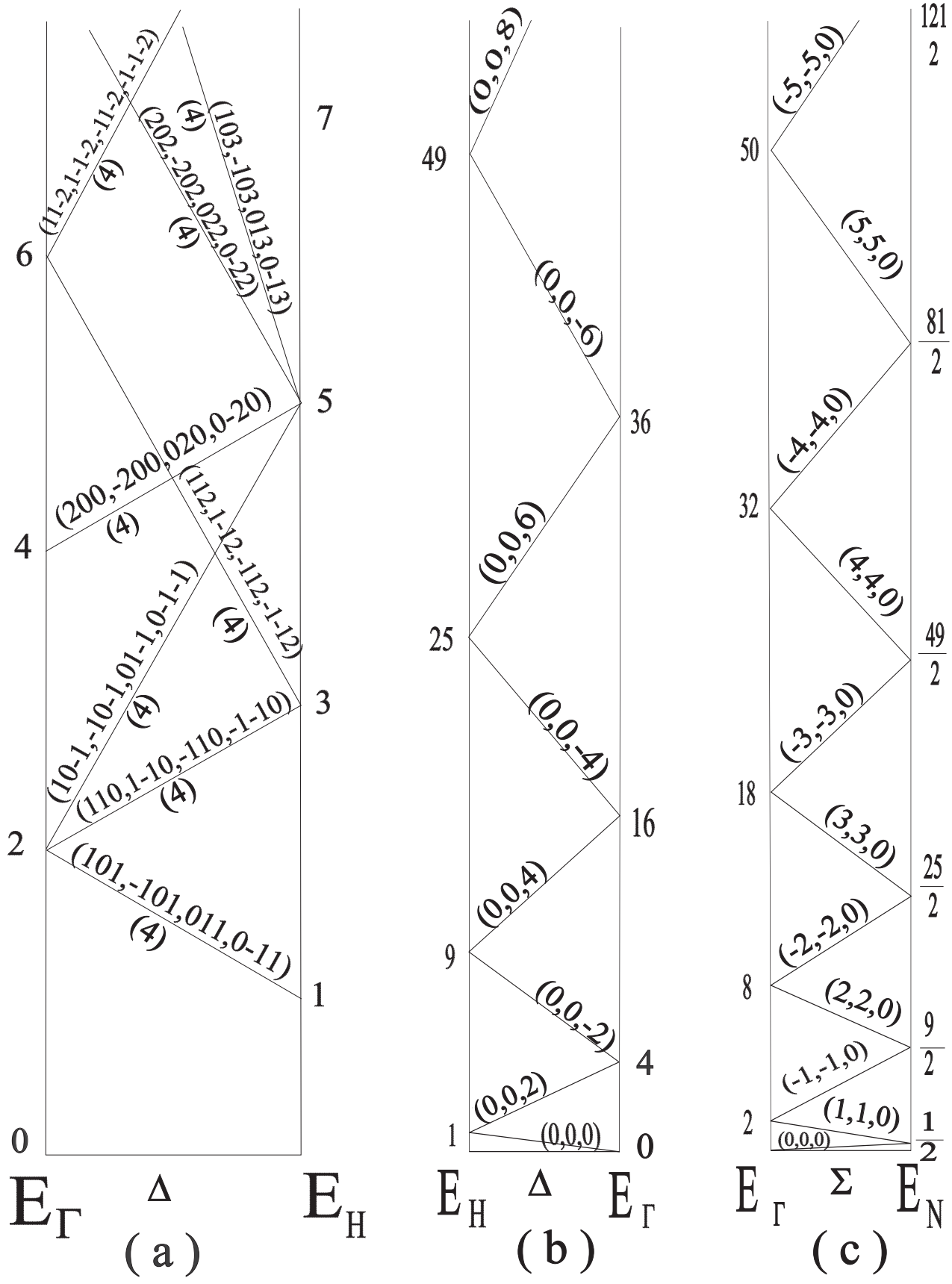
20-2,1-12,1-1-2)
(6)
(112,11-2,002,00-2,
220,-1-10)
(6)
(-101,121,-10-1,12-1)
(4)
(2-11,2-1-1)
(2)
(0-11,0-1-1,21-1,211)
(4)
(020,-110)
(2)
(011,01-1)
(2)
(200,1-10)
(2)
(101,10-1)
(2)
(000,110)
(2)
E_M
G
E_N
(b)

Figure 4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2
0
7
5
3
1
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(4)
(202,-202,022,0-22)
(4)
(103,-103,013,0-13)
(200,-200,020,0-20)
(4)
(112,1-12,-112,-1-12)
(4)
(10-1,-10-1,01-1,0-1-1)
(4)
(110,1-10,-110,-1-10)
(4)
(101,-101,011,0-11)
(4)
E Γ
Δ
E H
(a)
49
25
9
1
36
16
4
0
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(0,0,-6)
(0,0,6)
(0,0,-4)
(0,0,4)
(0,0,-2)
(0,0,2)
(0,0,0)
E H
Δ
E Γ
(b)
50
32
18
8
2
121/2
81/2
49/2
25/2
9/2
1/2
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(-4,-4,0)
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(2,2,0)
(-1,-1,0)
(1,1,0)
(0,0,0)
E Γ
Σ
E N
(c)

Figure 5